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The use of numerical method in an electric grid coupled to a wind farm to compare different kinds of flexible AC transmission systems

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The PSAT software was used in this study to analyse and compare the performance of hybrid compensators such as SSSC-STATCOM (controllers), TCSC-SVC (compensators), and UPFC in an electric grid coupled to a wind farm. The flexible AC transmission system (FACTS) technology is used to provide a continual power flow and to provide new ways to control the electric system network. In the FACTS devices, the UPFC (Unified Power Flow Controller) is one of the most adaptable, flexible, and complicated power electric devices. The active and reactive power flows and the local voltage on the bus can be regulated by UPFC; it can also resolve the problem of harmonics. The TCSC (Thyristor-Controlled Series Capacitor) consists as a series-compensating capacitor shunted by a thyristor-controlled reactor. The SVC (Static Var Compensator) is the first shunt generation FACTS controller. We can observe that the UPFC controller has an effective power flow control, shorter setting time and a shorter overshoot. The UPFC obtained a well-known reputation for high controllability in power systems. The multilevel Unified Power Flow Controller can be operated in Static Synchronous Compensator (STATCOM), in Static Synchronous Series Compensator SSSC and exactly in the UPFC compensator. The results of this research compare the hybrid controllers and investigate the effects of TCSC-SVC, SSSC-STATCOM, and UPFC on voltage, phase angle stability, and the active and reactive power in the tested system. The purpose of this comparison is to improve dynamic voltage regulation, especially when the utilisation of nonlinear loads and the presence of fault and breaker rise. These hybrid controllers have been shown to outperform series or shunt compensators; however, when compared to hybrid compensators SSSC-STATCOM, TCSC-SVC, and UPFC, the results employing the numerical method in the UPFC are more significant. The UPFC is the best hybrid controller in this study, and the compensators SSSC-STATCOM outperform the controllers TCSC-SVC.

Keywords: numerical method, electric grid, wind farm, FACTS

INTRODUCTION

The four primary components of a power system are the power station, the transmission line, the distribution network, and loads [1]. In the past years, the rise in peak load demand and inter-utility power transfers have been raising concern regarding system voltage security. Voltage collapse has been deemed responsible for a number of large problems, and extensive research is being conducted to better understand the voltage phenomena. The ability of power systems to maintain adequate voltage magnitude so that when the nominal load of the system is increased, the actual power transmitted to that load also increases, so voltage at its stable value must be maintained. The inability to satisfy the demand for reactive power is the cause of primary voltage instability. The reason of system voltage collapse is the voltage instability that occurs when the voltage of the system falls to a point where it cannot be recovered. Voltage collapse can cause the system to lose power partially or completely. The two types of voltage stability based on simulation time are static voltage stability and dynamic voltage stability. Because it involves just the solution of algebraic equations, static analysis is less computationally demanding than dynamic analysis. The majority of research that needs the identification of the voltage stability limit for a variety of pre-contingency and post-contingency conditions benefits from static voltage stability. Voltage instability is caused by a reactive power imbalance. Insufficiency of active and reactive power can be caused by industrial or domestic uses of converters, arc furnaces, solar inverters, fluorescent bulbs, asymmetrical and shock-loading structures, etc. [2–5].

The studies in references [6–7] discuss the wind energy generation technologies, which are gaining a lot of interest due to their environmental benefits. The change in voltage (drop voltage or excess voltage) at the common point of connection is the primary cause of wind farm disconnection (PCC). Disconnections caused by the tripping of the protective devices of a wind farm will not be tolerated. Some constructors are required to create new systems for the purpose of keeping wind farms coupled to the network in the occurrence of a power outage.

We can see in the literature [8–12] that high power electronic equipment and flexible AC transmission System (FACTS) devices have been widely deployed in power systems in recent years. When compared to traditional technology, they have a faster dynamic response and more advanced applications. FACTS was proposed by the Electric Power Research Institute (EPRI) in the late 1980's as a new method to solving the problem of developing and operating power systems. The IEEE defines a FACTS as an electronic-based power system with other static equipment that controls one or more AC transmission system parameters to improve controllability and power transfer capabilities. FACTS devices have recently been used for flexible power flow management, secure loading, and power system oscillation damping. Some of them are also utilised to increase the transient and dynamic stability of wind power generation systems. In the event of large disturbances and faults, transient stability control plays a critical role in guaranteeing the stable operation of power systems. FACTS has a well-deserved reputation for improving power system controllability through the use of power electronic devices. The first application of FACTS devices is the rapid power flow regulation, which can help in improving stability and security margins. These devices impose their impact by controlled series compensation, shunt compensation, or phase shift regulation. FACTS devices are used to control voltage, current, or impedance. The power electronic enables extremely fast reaction times of less than one second. Controllability can help to prevent high expenditures associated with power system growth, such as upgrading or building substations and power transmission lines, in most cases. FACTS devices improve the use of existing installations by better adapting to diverse operational conditions.

The unified power flow controller (UPFC) was introduced in the 1990s and is based on the concept of combined series-shunt FACTS controller. It has the potential to improve the power flow control with stability and reliability, in addition to the ability to simultaneously control all transmission parameters without affecting the power flow of transmission lines, such as voltage, line impedance, and phase angle [13]. A shunt capacitor bank and a thyristor-controlled shunt reactor (TCR) make up the static VAR compensator (SVC) system; the capacitors in the capacitor bank could be permanently connected or switched with a thyristor-switched capacitor (TSC). The latter organises compensation for reactive power into logical categories. The system TCR can also absorb continuous reactive power. If absorption of the whole reactive power is needed, all TSCs must be disconnected. The system can obtain continuous reactive power production with coordinated control TSC and TCR [14]. A series compensatory capacitor is shunted by a TCR in a Thyristor-Controlled Series Capacitor (TCSC); it is a part of the FACTS system, and it has demonstrated its potential in studies. The use of a thyristor with natural commutation and low frequency switching offers advantages in TCSC. As a result, the cost, complexity, and power loss have all decreased in reference [15]. The static synchronous series compensator (SSSC) can control active power in electric line transmission over a small range by injecting reactive power with the stored energy in capacitor DC link, whereas the static synchronous compensator (STATCOM) can control the bus voltage in electric line transmission by injecting reactive energy. The most functional and flexible equipment, UPFC, is a technology that has evolved for controlling and optimising power flow in power transmission systems. It combines the benefits of both series and shunt converter-based FACTS devices, allowing it to perform voltage control, series and shunt compensation, and angle of phase adjustment simultaneously. As a result, the UPFC may adjust power, both active and reactive, on the compensated transmission line independently as shown in [16]. This study compares the hybrid controllers SSSC-TCSC, SVC-STATCOM, and UPFC for regulating the flow of active and reactive power in a network coupled to a wind farm. PSAT software is used to calculate transient and steady state calculations utilising the numerical method, in addition to a dynamic simulation.

THE ELECTRICAL GRID

Voltage is a quality characteristic of electricity, and its variation must not exceed specified limits set by existing standards based on the nominal voltage of the network. Unlike frequency, all mesh points have the same value. The voltage level in the network varies a great deal, based in terms of both active and reactive power flows:

$$\Delta U = U_1 - U = \underline{Z}.\underline{I} = (R + jX).\underline{I} =$$

$$\frac{(R + jX).(P - jQ)}{U} = \frac{P.R + QX}{U} +$$

$$j\frac{P.X + Q.R}{U} = \Delta U + j\delta U. \quad (1)$$

where

ΔU: The longitudinal component the voltage drops;

δU: The width wise component of the voltage drops.

The major voltage control means in electrical networks can be deduced by:

- reactive power flow changes;
- electrical grid parameter changes: R, X;
- insertion of additional voltages.

Synchronous compensators, coil shunts, synchronous motors and generators, derivation

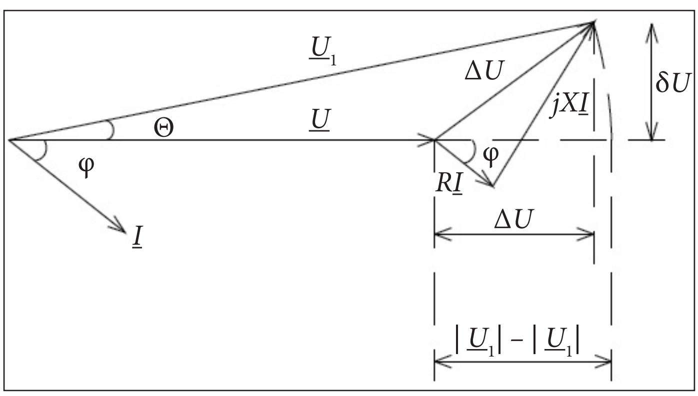

Fig. 1. Adjusting voltages in electrical networks [17]

capacitor banks, and FACTS are some of the mechanisms available to produce or absorb reactive power when reactive power flows change [17].

MODEL OF A WIND TURBINE

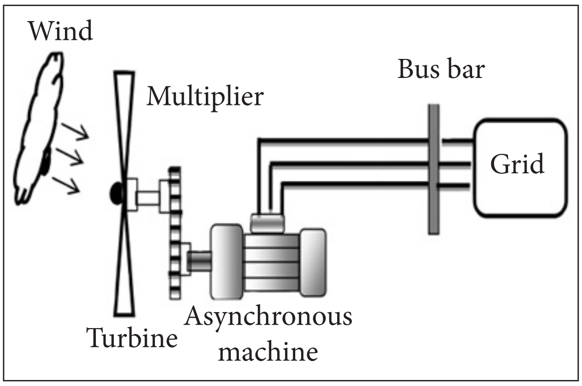

Fig. 2. Wind system [7]

The wind action causes the paddle to rotate the wind system at a set speed and angle, converting wind energy into mechanical energy that drives the generator. Wind turbines convert wind energy into mechanical energy using a complicated aerodynamical process that is difficult to correctly describe. Figure 3 illustrates the variation in the wind speed. The equation of mechanical power in wind system capture, according to Betz law [6–7, 14], is the following

$$P_m = \frac{1}{2}\rho A V_w^3\, C_p. \tag{2}$$

Where A is the rotor swept area, V_w is the wind speed, and C_p is the coefficient of performance. Equation (3) represents the generator tip speed ratio in terms:

$$\lambda = \frac{\omega_m R}{V_w}. \tag{3}$$

The torque on the shaft of a wind turbine:

$$T_m = \frac{1}{2}\rho\pi R^5 \frac{\omega_m^3}{\lambda^2} C_p. \tag{4}$$

The maximum power point tracking (MPPT) algorithm maintains the maximum power coefficient $C_p = C_{p\max}$, which corresponds to λ_{opt}, where:

$$\omega_{ref} = \frac{V_w \lambda_{opt}}{R}. \tag{5}$$

As a result, the maximum power associated with $C_{p\max}$ is represented by:

$$\omega_{ref} = \frac{V_w \lambda_{opt}}{R}. \tag{6}$$

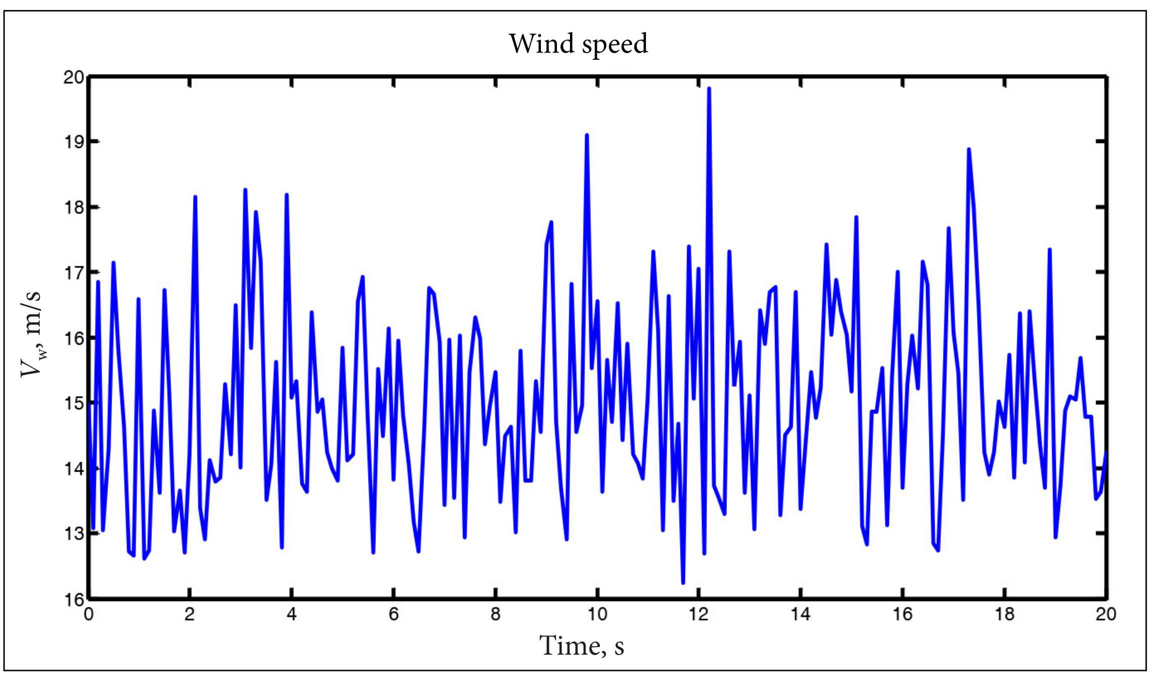

Fig. 3. Wind speed

MODEL OF FACTS COMPENSATORS

Many of the stability boundaries can undoubtedly be overcome with the FACTS technology, with the ultimate limits being thermal and dielectric. FACTS controllers are divided into three categories: series controllers, shunt controllers, and phase angle controllers. Combination controllers are also known as combined series-series compensators and combination series-shunt controllers [18]. The fixed capacitor with a thyristor-controlled reactor and the thyristor switched capacitor are the two most common SVC shunt controller configurations. The second TSC-TCR of these two arrangements minimises standby losses [19]. The TCSC device consists of two anti-parallel thyristors connected in series with one inductor (L) and connected in parallel with one capacitor (C). Thyristor controlled reactor is a combination of an inductor in series with two anti-parallel thyristors [20]. A shunt-connected reactive power compensation device used on an alternating current electrical transmission network is known as a Static Synchronous Compensator. It can generate and absorb reactive power, and its output may be adjusted to control specific power characteristics. The voltage source converter (VSC), coupling transformer, controller, and DC energy storage are the four major components of the STATCOM [21]. The inverter-based series compensator, also known as the SSSC, provides a number of advantages over the TCSC. These include the deletion of bulky passive components, symmetric capability in both capacitive and inductive operating modes, and the ability to link a DC energy source to the AC network to exchange real power [22].

The interline power flow controller (IPFC), which balances both reactive and active power flows on the lines, is an example of a combined series-series controller. A combined series-shunt controller can be configured in two ways: one with two separate series and shunt controllers that work together, and the other with interconnected series and shunt components. In either configuration, the shunt component injects a current into the system, whereas the series component injects a voltage [23]. The UPFC is the most adaptable member of FACTS family, which controls power flow on power grids using power electronics. A shunt controller (STATCOM) and a series controller (SSSC) are employed in the UPFC, which are coupled via a shared DC bus. In theory, the UPFC can maintain voltage, increase power flow, and improve dynamic stability, all in one device as shown in [24].
FACTS devices with controllable parameters [18] are shown in Table 1 and Fig. 4.

A two-bus system i and j are used to represent the power transmission line. The P, called active power sent between bus nodes i and j is calculated as follows:

Table 1. **Comparison of various types of FACTS devices**

FACTS	Parameters	Parameter controlled
STATCOM	Dynamic and transient stability, voltage stability, and damping oscillations are all examples of voltage control.	Q
SVC, TCR, TCS, TRS	Transient and dynamic stability, damping oscillations are all examples of voltage control.	Q
SSSC	Dynamic and transient stability, damping oscillations, voltage stability, and current control.	P
TCSC, TSSC	Fault current limiting, dynamic and transient stability, damping oscillations, voltage stability, and current control.	P
TCSR, TSSR	Fault current limiting, dynamic and transient stability, damping oscillations, voltage stability, and current control.	P
IPFC	Damping oscillations, dynamic and transient stability, voltage stability.	P, Q
UPFC	Voltage control, dampening oscillations, transient and dynamic stability, Var compensation.	P, Q

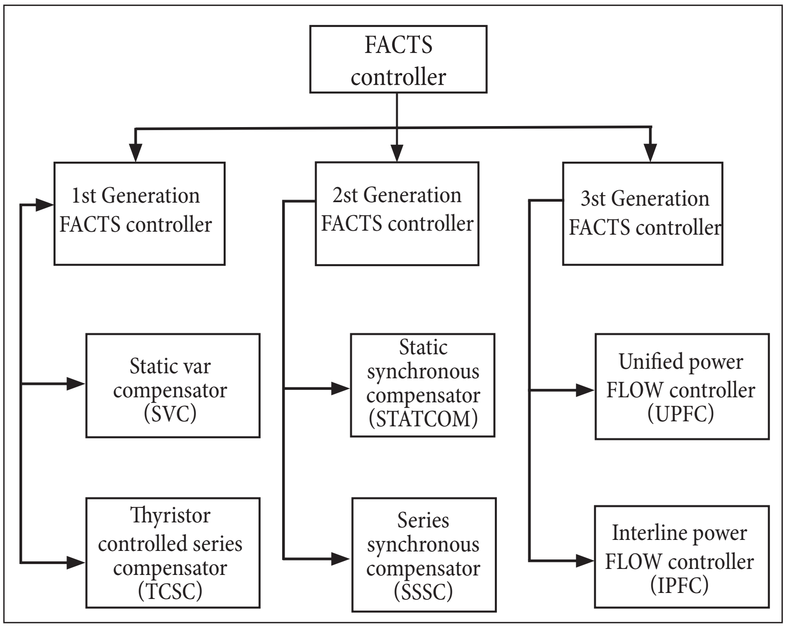

Fig. 4. FACTS controllers [13]

$$P = \frac{V_j * V_i}{X} \sin(\theta_i - \theta_j), \tag{7}$$

where V_i and V_i are the voltages at the nodes i and j, $(\theta_i - \theta_j)$ the voltage angle, and X is the line impedance. The voltages at a node, the impedance between nodes, and the angle among the end voltages can all be adjusted to influence the power flow. The reactive power is calculated by [18, 25]:

$$Q = \frac{V_i^2}{X} - \frac{V_j * V_i}{X} \cos(\theta_i - \theta_j). \tag{8}$$

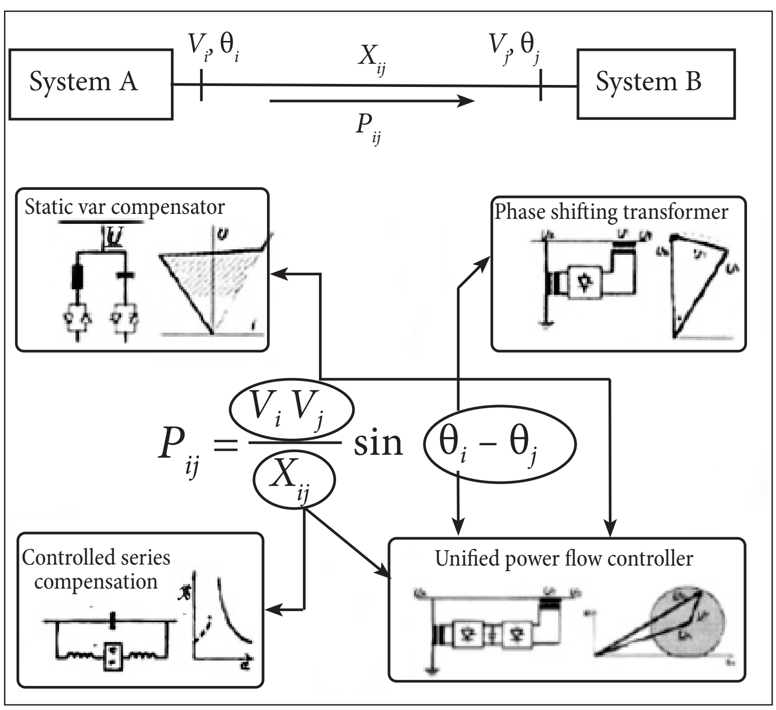

Fig. 5. FACTS active power and controlled variable [18]

Line reactance is controlled by SSSC or TCSC in transmission lines, while reactive power is controlled by STATCOM or SVC. UPFC, on the other hand, regulates all power flow characteristics such as phase angle, bus voltage, and line impedance. As a result, optimal choice and allocation of FACTS devices are attained in the power system. FACTS controllers are created on the basis of the compensator technology concept, which increases the dependability, stability, and power flow control. This controller was created in order to address issues with the power system. However, some controllers have the ability to solve several problems in a power system, whereas others are confined to solving a single problem [13].

NEWTON-RAPHSON METHOD OF POWER FLOW

Power flow analysis is required for utility planning, operation, economic scheduling, and power exchange. Many other analyses, such as transient stability, optimal power flow, and contingency studies, require power flow analysis. The magnitude and phase angle of voltage at each bus, the active and reactive power flow in each transmission line are the most important aspects of power flow analysis. A multi-input and multi-output system could be used to describe the power flow problem. Each input could, in some way, influence each of the outputs. Consequently, appreciating the association between these variables becomes more challenging [26]. One of the most fundamental concerns in the power electrical system is the power flow. The primary idea behind an electric power flow analysis is to determine the voltage at various bus bars, power flow and power injection on lines, line losses, and total system power losses under various operating situations. The Newton-Raphson (N-R), Gauss-Seidel (G-S), and Fast Decoupled (F-D) methods are prominent numerical methods for solving power flow problems [27].

The Newton-Raphson power flow method is an iterative method for solving the power flow problem that is based on linearisation. The computed injected power at each bus in a system is updated in each step, starting from the initial solution. In each Newton-Raphson iteration, the linear problem $Jx = [\Delta P, \Delta Q]$ is formed and solved. The Newton-Raphson technique iteratively updates the initial voltage estimate until the algorithm converges, or a maximum number of iterations are achieved, starting with the initial voltage estimate. If the difference between the scheduled power injections $S_{i,s} = P_{i,s} + jQ_{i,s}$ and the calculated injections $S_i = P_i + jQ_i$ for each non-slack bus is less than a given tolerance, convergence is accomplished. The injections S_i are calculated based on the estimated current voltage. The mismatch equations (9) and (10) express the discrepancy between the scheduled injection and the calculated estimate:

$$\Delta P_i = P_i - P_{i,s}, \tag{9}$$

$$\Delta Q_i = Q_i - Q_{i,s}. \tag{10}$$

Using an initial guess and a particular voltage magnitude and angle, the P and Q power at a specific bus is determined. To solve these nonlinear equations, iteration approaches were used (Gauss-Seidel and Newton-Raphson). Newton-Raphson was more efficient and reliable, and it calculated powers in the following way:

$$P_i = \sum_{j=1}^{N} |V_i||V_j|(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}), \tag{11}$$

$$Q_i = \sum_{j=1}^{N} |V_i||V_j|(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}). \tag{12}$$

The net active and reactive power injections at bus i with the voltage magnitude $|V_i|$ are (P_i and Q_i). Similarly, $|V_j|$ represents the magnitude of the voltage at bus j. The voltage angle difference between buses i and j is ($\theta_{ij} = \theta_i - \theta_j$). The power flow problem is linearised using Taylor series, which may then be given in the matrix form as:

$$J\begin{bmatrix} \Delta V_a \\ \Delta V_m \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}, \tag{13}$$

where J is called the Jacobian matrix, the algebraic calculations are in [28–29], ΔP and ΔQ represent the partial derivatives.

$$J = \begin{bmatrix} \dfrac{\partial P}{\partial V_a} & \dfrac{\partial P}{\partial V_m} \\ \dfrac{\partial Q}{\partial V_a} & \dfrac{\partial Q}{\partial V_m} \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix}. \tag{14}$$

In each step, the partial derivatives ($\partial P/\partial V_a$), ($\partial Q/\partial V_a$), ($\partial P/\partial V_m$) and ($\partial Q/\partial V_m$) for each *PQ* bus must be determined. Similarly, the partial derivatives ($\partial P/\partial V_a$) and ($\partial Q/\partial V_a$) for each *PV* bus must be determined [26, 30].

SIMULATION OF THE TESTED SYSTEM USING PSAT

Power system analysis toolbox (PSAT) is an open-source toolbox that uses MATLAB to do dynamic and static analysis and to control power systems. It has a number of characteristics, including power flow analysis, optimal power flow, analysis, signal stability, and simulation. The model library SIMULINK is used for network topology design, or data files are edited directly. PSAT provides a variety of models, both dynamic and static, including bus, transformer, transmission line, PV, PQ, and balancing node, circuit breaker, line fault, constant power load, synchronous motor, and induction motor to increase the accuracy of analysis. Based on their research interests, users can write and alter the source code for research purposes [31–33]. A system was constructed with PSAT software to compare the performance of SVC-TCSC, STATCOM-SSSC compensators and UPFC controllers in a network coupled to a wind farm and influenced by fault and breaker, which can accurately lower grid power performance. The model included 21 bus and eight synchronous generators to provide active and reactive power to the system in order to verify the suggested method using numerical methods.

RESULTS AND ANALYSIS USING PSAT

The numerical method is a reliable and effective method for solving difficulties in the power flow.

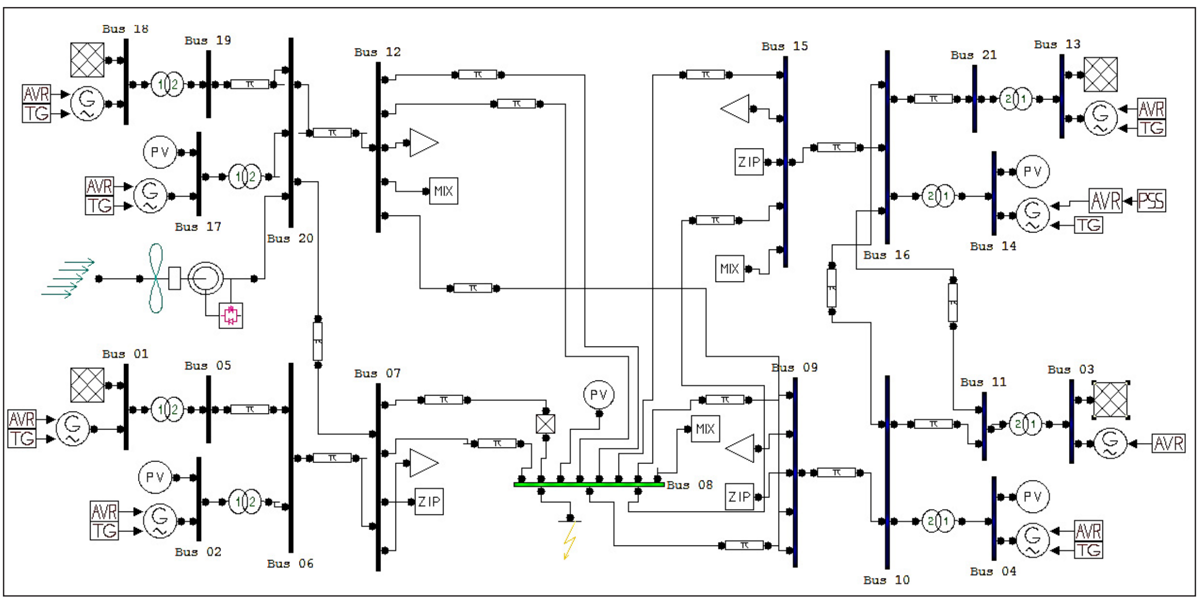

Fig. 6. The tested system using PSAT

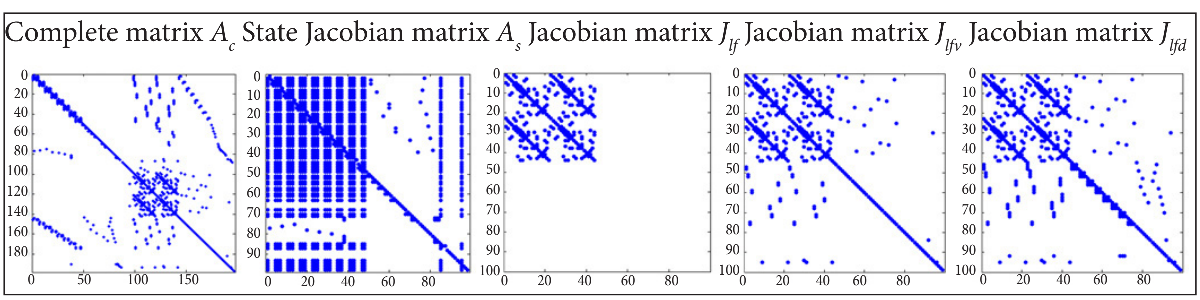

Fig. 7. Numerical results of 21-bus tested system using TCSC-SVC compensators

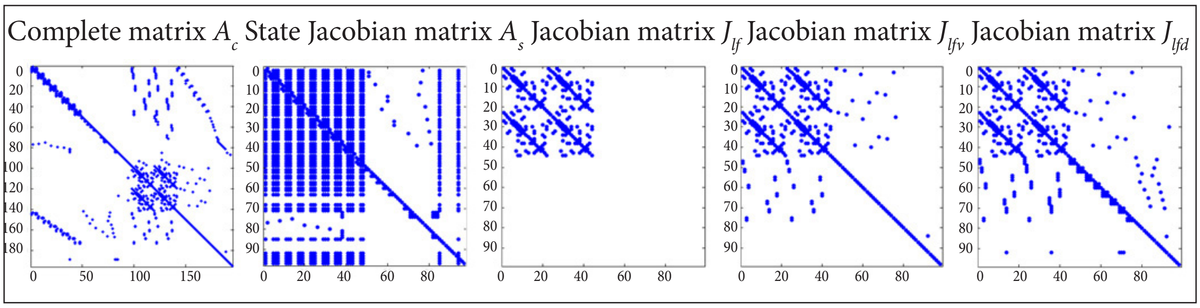

Fig. 8. Numerical results of 21-bus tested system using SSSC-STATCOM compensators

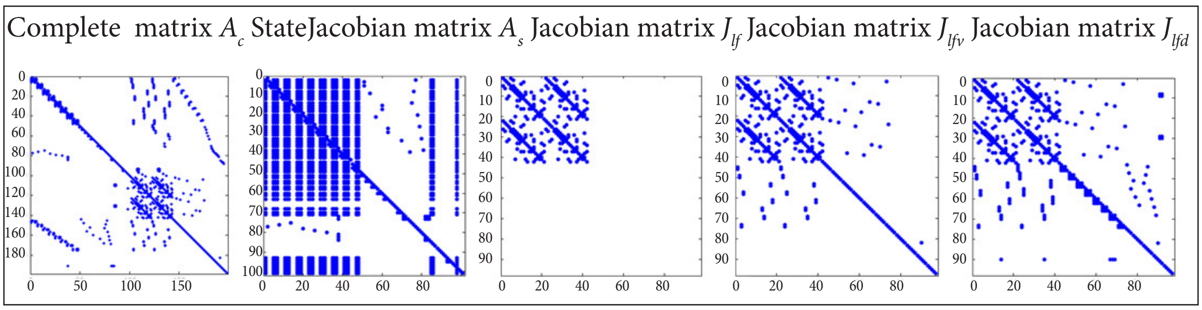

Fig. 9. Numerical results of 21-bus tested system using UPFC compensator

Iterative solving voltage and flow problems is the objective of this approach. The Jacobian calculus defines the linearised approach, and the linear problem must be solved.

The major goal of this section was to assess the performance of hybrid (TCSC-SVC), (SSSC-STATCOM) compensators and the UPFC controller in an electric grid connected to a wind

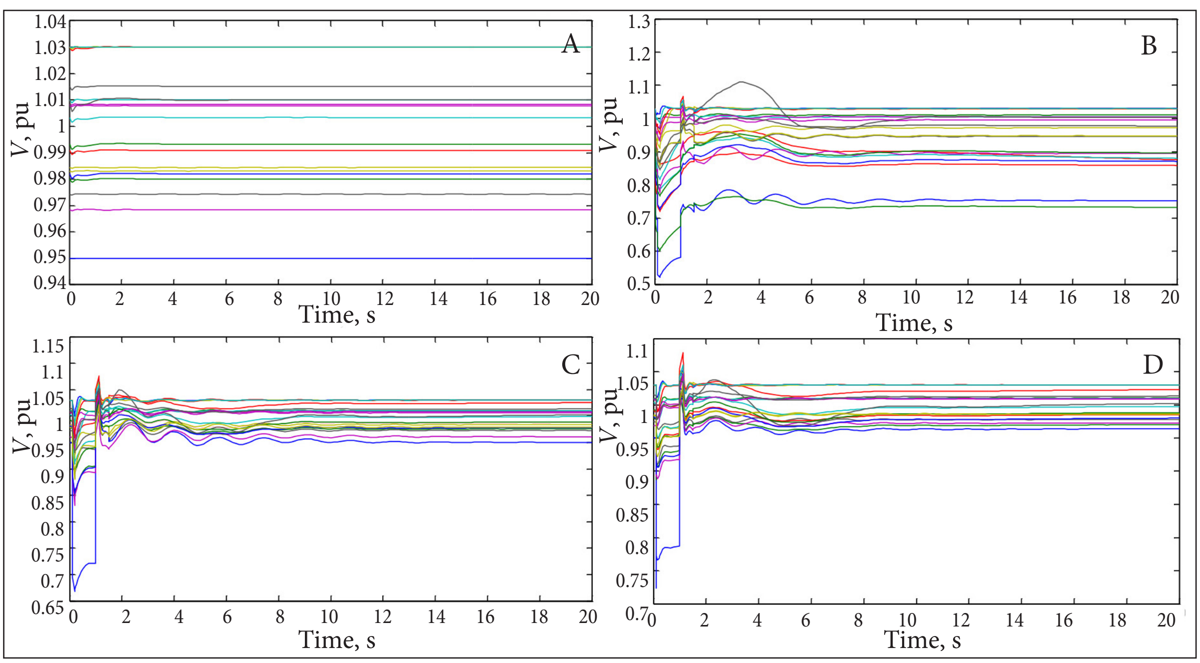

Fig. 10. Voltage in a 21-bus system

(A) The tested system without fault, breaker, and FACTS (ideal), (B) the tested system with TCSC-SVC, (C) the tested system with SSSC-STATCOM, (D) the tested system with UPFC.

farm with the influence of fault and breaker in the tested electric system shown in Fig. 6. The simulation findings reveal that, depending on the location of the wind farm, wind power integration can have a favourable or negative impact on small signal stability of the power system, but fault and breaker can directly influence the power system by greater oscillations.

Figs 10 to 13 compare the hybrid controllers and examine the impact of TCSC-SVC,

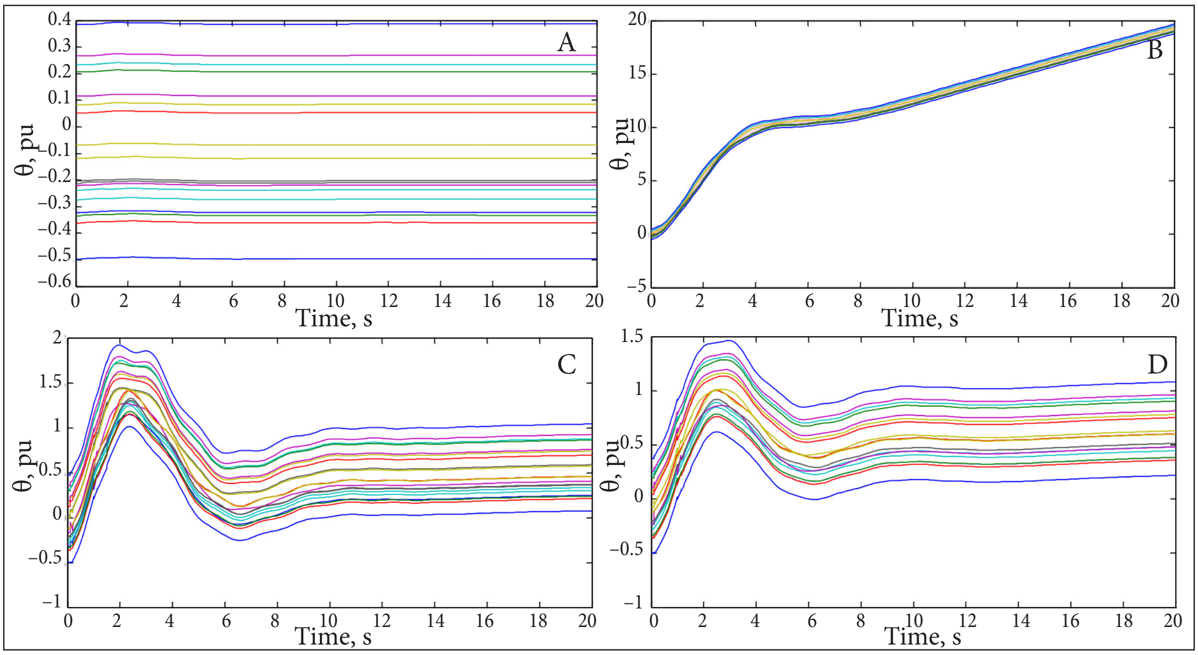

Fig. 11. Phase shift in a 21-bus system

(A) The tested system without fault, breaker, and FACTS (ideal), (B) the tested system with TCSC-SVC, (C) the tested system with SSSC-STATCOM, (D) the tested system with UPFC.

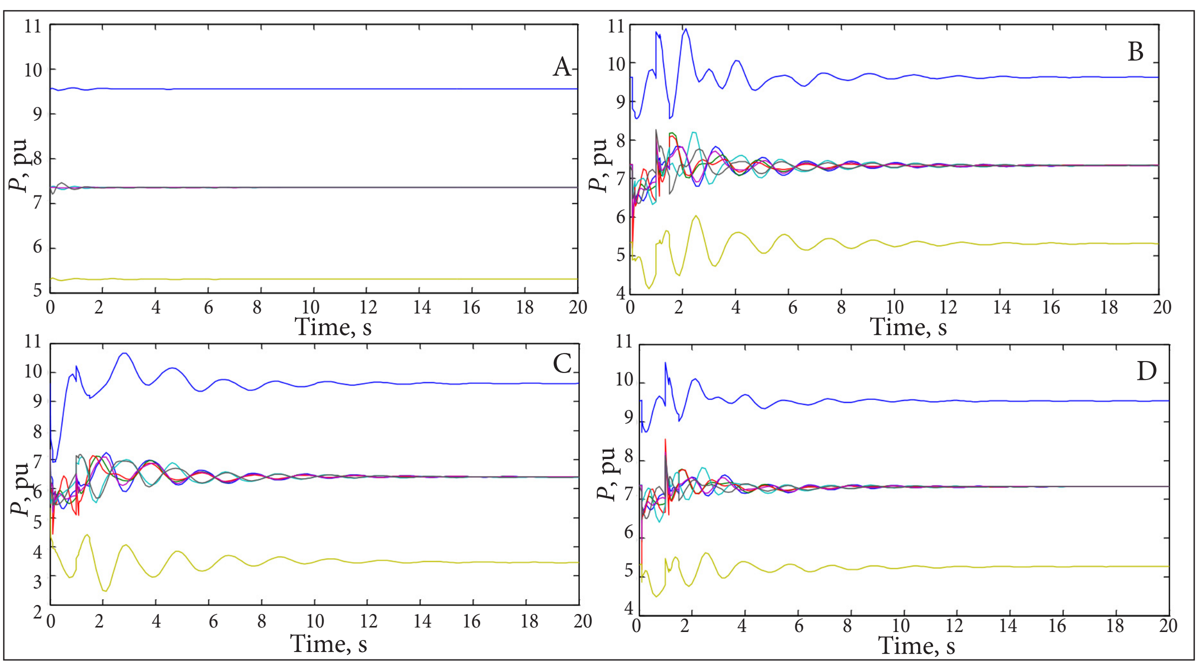

Fig. 12. Active power provided from eight generators

(A) The tested system without fault, breaker, and FACTS (ideal), (B) the tested system with TCSC-SVC, (C) the tested system with SSSC-STATCOM, (D) the tested system with UPFC.

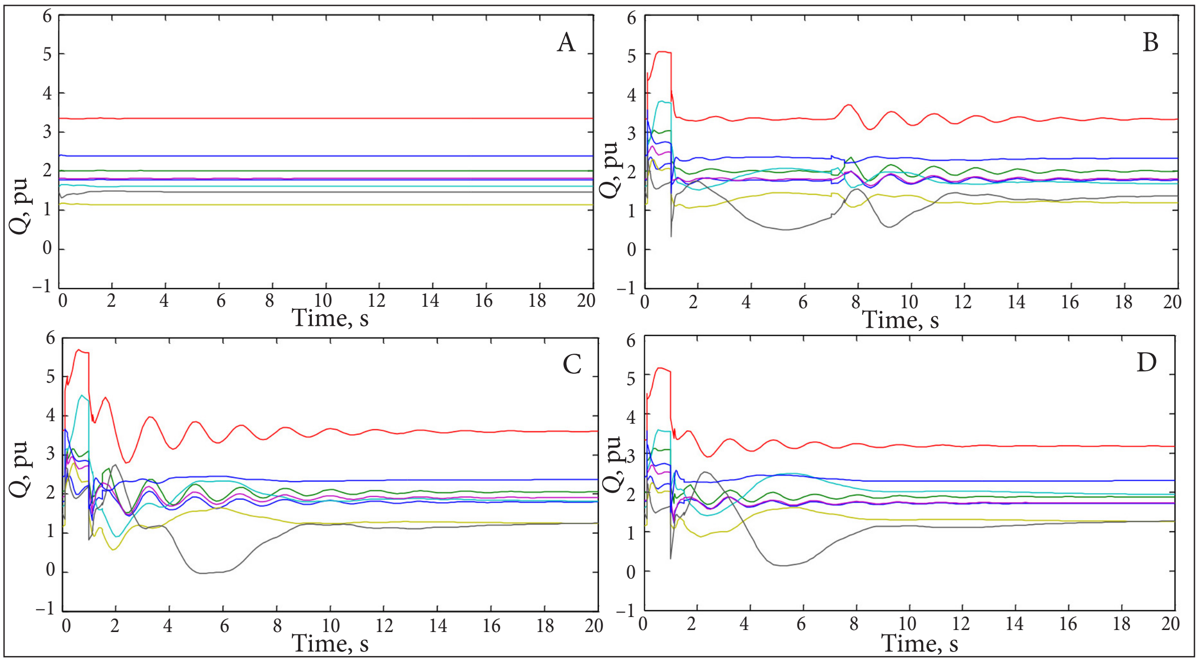

Fig. 13. Reactive power provided from eight generators

(A) The tested system without fault, breaker, and FACTS (ideal), (B) the tested system with TCSC-SVC, (C) the tested system with SSSC-STATCOM, (D) the tested system with UPFC.

Table 2. **Results of the tested system without FACTS, with TCSC-SVC, SSSC-STATCOM, and UPFC**

i to *j* ideal system	*P* Flow (MW)	*Q* Flow (MVar)	*P* Loss (MW)	*Q* Loss (MVar)	*i* to *j* (TCSC-SVC)	*P* Flow (MW)	*Q* Flow (MVar)	*P* Loss (MW)	*Q* Loss (MVar)
5–6	73.49	8.77	1.34	1.30	5–6	73.43	8.98	1.34	1.30
20–12	144.79	10.76	2.18	2.16	20–12	158.70	15.13	2.65	2.63
8–15	14.73	–1.47	0.28E-14	0.26	8–15	14.56	–1.19	0.28E-14	0.26
12–8	8.64	0.28	0.08	–0.08	12–8	13.16	–0.22	0.20	0.03
21–16	53.04	6.78	0.69	0.65	21–16	53.11	7.79	0.70	0.65
16–15	159.19	8.11	2.57	2.55	16–15	158.91	7.54	2.58	2.57
15–8	–14.17	4.63	2.64	0.08	15–8	–14.04	4.22	0.25	0.07
12–8	8.64	0.28	0.08	–0.08	12–8	13.16	–0.22	0.20	0.03
10–16	–26.71	0.58	0.07	0.05	10–16	–27.24	1.45	0.07	0.05
12–9	23.80	–0.95	0.66	0.48	12–9	28.17	–0.27	0.94	0.76
. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Total loss			15.41	22.00	Total loss			16.54	23.03
***i* to *j* (SSSC-STATCOM)**	***P* Flow (MW)**	***Q* Flow (MVar)**	***P* Loss (MW)**	***Q* Loss (MVar)**	***i* to *j* (UPFC)**	***P* Flow (MW)**	***Q* Flow (MVar)**	***P* Loss (MW)**	***Q* Loss (MVar)**
5–6	63.99	8.19	1.04	1.00	5–6	73.30	8.28	1.33	1.29
20–12	132.75	4.70	2.20	2.19	20–12	143.73	9.41	2.13	2.11
8–15	11.83	–0.69	0.00	0.36	8–15	13.75	–0.27	0.28E-14	0.22
12–8	9.43	1.04	0.29	0.16	12–8	8.64	–0.58	0.08	–0.09

Table 2. **(Continued)**

i to *j* (SSSC-STATCOM)	*P* Flow (MW)	*Q* Flow (MVar)	*P* Loss (MW)	*Q* Loss (MVar)	*i* to *j* (UPFC)	*P* Flow (MW)	*Q* Flow (MVar)	*P* Loss (MW)	*Q* Loss (MVar)
21–16	34.54	2.94	0.54	0.50	21–16	52.72	7.95	0.69	0,64
16–15	144.71	2.17	2.66	2.65	16–15	160.69	5.50	2.64	2.62
15–8	–10.67	1.09	0.36	0.23	15–8	–13.37	2.93	0.22	0.04
12–8	9.43	1.04	0.29	0.16	12–8	8.64	–0.58	0.08	–0.09
10–16	–17.16	–3.10	0.17	0.15	10–16	–25.14	–0.35	0.06	0.04
12–9	20.95	1.36	0.88	0.75	12–9	22.13	–0.02	0.57	0.38
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
Total loss			15.34	21.94	Total loss			15.29	21.89

SSSC-STATCOM, and UPFC on voltage, phase angle stability in 21 bus, active and reactive power in eight generators of the tested system. The goal of this comparison is to improve dynamic voltage regulation, particularly as the use of nonlinear loads increases, as well as the presence of fault and breaker. These hybrid controllers are proven to perform better than series or shunt compensators; however, UPFC has a considerably superior performance than SVC-TCSC and STATCOM-SSSC. In this study, the compensators STATCOM-SSSC results outperform the controllers SVC-TCSC. Table 2 shows the results of simulations of the above system using various types of hybrid compensators. In terms of loss reduction, voltage profile, active and reactive compensation, FACTS performs better than other compensators, although UPFC works better than series and shunts compensators.

CONCLUSIONS

Using a numerical method, a comparison of TCSC-SVC, SSSC-STATCOM, and UPFC controllers in the network coupled to a wind farm is described in this research, the objective of which was to examine and compare the advantages and disadvantages of hybrid compensators. The UPFC control approach provides sufficient flexibility to achieve the appropriate level of stability and performance on rotor angle, speed, active and reactive power generators, as well as phase shift, voltage, and power buses. As can be seen, this controller has an effective power flow control, reduced setting time, and shorter overshoot. The UPFC obtained its well-known reputation for high controllability in a grid coupled to a wind farm. The multilevel UPFC can be operated in STATCOM, in SSSC, and especially in the UPFC device. We can also see that the controller SSSC-STATCOM has good results in terms of accuracy and exactitude compared to the TCSC-SVC compensator.

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SKAITMENINIO METODO TAIKYMAS SU VĖJO JĖGAINE SUJUNGTAME ELEKTROS TINKLE, SIEKIANT PALYGINTI ĮVAIRIAS LANKSČIŲ KINTAMOSIOS SROVĖS PERDAVIMO SISTEMŲ RŪŠIS