Application of FACTS Devices for Damping of Low-Frequency Oscillations in Azerbaijan's Power System

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***Abstract* — The structure of Azerbaijan's power system is characterized by its substantial heterogeneity, i.e., unevenly loaded transmission lines in a large number of power flows, limited possibility of wheeling through backbone tie-lines due to the bypass power grid operation. The use of Flexible AC Transmission System (FACTS) devices makes it possible to impart active properties to a passive electrical network and thus provide flexible control over the operation of the power system. FACTS devices increase the transfer capability of the electrical network. It is known that a system of automatic control of damping can be used to augment the stability of power systems. Damping may be achieved using other devices installed with the express purpose of stability augmentation. Disruption of stability of the power system is the result of loss of synchronism of the generator rotor because of insufficient damping torque of low-frequency oscillations (usually 0.1–1.0 Hz) and local oscillations (1–3 Hz). We propose improving the damping of low-frequency oscillations by placing a unified power flow controller in the power system. The efficiency of the application is demonstrated through a case study of a 220 kV – 330 kV – 500 kV network.**

***Index Terms*: : power system, FACTS devices, unified power flow controller, damping of low-frequency oscillations, static synchronous compensator.**

I. Introduction

FACTS devices have mainly been used to address various tasks of power system steady-state operation, such as voltage regulation, power flow management, and transfer capability enhancement.

As a rule, the installation of FACTS devices for the sole purpose of augmenting power system stability is economically unfeasible.

This study examines reactive power distribution using different types of FACTS with electronic devices. We analyze the problem of stabilizing the power system by using a static synchronous compensator (STATCOM) to increase the damping of electromechanical oscillations of the power system and control the system voltage. The proposed combined control by STATCOM and Unified Power Flow Controllers (UPFC) through online coordinated control to dampen oscillations improves stability of the power system. These devices must be supplemented with an auxiliary controller for damping low-frequency oscillations.

The structure of Azerbaijan's power grid is characterized by its pronounced heterogeneity, due to which for a large number of power flows there is an uneven load of transmission lines observed, in connection with which the operating conditions of the bypass power grid can limit the capabilities of wheeling along the backbone links.

The use of FACTS devices makes it possible to impart active properties to the passive power grid and thereby implement flexible control over power system operating conditions [1–4].

II. Application of FACTS Devices For Damping Of Low-Frequency Oscillations in Power Systems

The main advantage of the STATCOM and Unified Power Flow Controller (UPFC) is their speed. The time of transition from the maximum reactive power generation to the maximum consumption is less than 0.01 s.

The stability of power systems depends on complex interrelationships, and it is the main challenge facing the power system.

The power system may cease to provide adequate damping for cross-zone oscillations and variation of voltage profile. The use of FACTS devices can contribute to effective damping of low-frequency oscillations and improve bus voltage levels.

The unified power flow controller is the most promising device in the FACTS concept. It has the ability to adjust three control parameters, i.e., busbar voltage, transmission

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http://dx.doi.org/10.25729/esr.2023.02.0004
Received March 13, 2023. Revised April 21, 2023.
Accepted May 13, 2023. Available online June 10, 2023.

line reactance, and phase angle between two busbars simultaneously or independently. The UPFC does this by controlling the in-phase voltage, quadrature voltage, and shunt compensation [3, 4].

The UPFC can control the three control parameters either individually or in appropriate combinations on its series-connected output, thereby maintaining reactive power support on its parallel input.

It is generally recognized that adding an additional controller to the UPFC can significantly improve the damping of the power system. Therefore, several control configurations have been proposed to address the task of oscillation damping.

Huang et al. attempted to use a UPFC placed on the transmission line of a two-zone system to damp the oscillation between sections [5].

A PI controller with multiple inputs and multiple outputs was proposed. The study shows that if more than one UPFC controller, such as a power flow controller, AC voltage controller, and DC voltage controller, are designed separately, the dynamic interaction between different control channels can disturb the stability of the system.

Mishra et al. developed various intelligent damping controllers for the UPFC to damp both local and cross-zone oscillations for a multi-machine system. The efficiency of such controllers was demonstrated and described in a fairly successful way [6].

FACTS devices allow solving a wide range of problems: from voltage regulation at the buses of a power grid and the redistribution of active and reactive power flows between networks of different voltage classes, to an increase in the degree of utilization of the transfer capability of the power grid [1–4].

The use of the STATCOM and UPFC for the sole purpose of damping frequency oscillations of the power system may prove economically unfeasible. At the same time, the steady state control produces a large economic effect.

III. Controlled and Uncontrolled Series Compensation Devices (SCD).

The use of SCDs makes it possible to increase the transfer capability of power lines and controlled cutsets, to redistribute active power flows across power lines, including those of different voltage classes, and to damp low-frequency power oscillations (if the SCD has a controlled part).

The use of phase-shifting devices (PSDs) enables voltage regulation at the installation site with respect to both the magnitude and the phase, while changing both active and reactive power on the corresponding power grid component.

Wide-area damping control (WADC) is a class of automatic control systems used to augment the stability of modern electric power systems known as smart grids. The controller is actuated by modulation of active or reactive power devices throughout the grid. Such actuators are most often pre-existing power system devices such as static VAR compensators (SVCs), which serve primary purposes, which are not directly related to the WADC application. However, damping may be achieved with the other devices installed with the express purpose of stability augmentation. The instability of a large power grid not equipped with WADC results from the loss of synchronism of the generator rotor and is usually treated as a generator (or a group of generators) oscillating along an undamped exponential trajectory because of inadequate damping torque.

A combination of the STATCOM and UPFC added to the dual-zone system significantly increases oscillation damping and augments power system stability.

This involves coordination between the STATCOM controller and UPFC and is taken into account to enhance system stability during transients and to regulate the system voltage.

The static synchronous series compensator (SSSC) is a flexible AC transmission system which consists of a voltage source inverter coupled with a transformer connected in series with a transmission line. This device can inject an almost sinusoidal voltage in series with the line. The injected voltage can be considered as an inductive or capacitive reactance connected in series with the transmission line. This feature can provide controlled voltage compensation. In addition, SSSC can reverse the power flow by injecting a sufficiently large series reactive compensating voltage [3], [4].

The UPFC uses solid-state devices that provide functional flexibility normally unattainable with a conventional thyristor-controlled system. The UPFC is a combination of a static synchronous compensator and a static synchronous series compensator that are coupled via a common DC voltage link.

IV. FACTS devices based on STATCOM and universal power flow controller

Power system stability is the ability of an electric power system under given initial operating conditions to restore the state of operating equilibrium after exposure to a physical disturbance, with most system variables constrained so that virtually the entire system remains intact.

The power system stabilizer (PSS) is generator control equipment that is used in feedback to amplify the damping of rotor oscillations caused by small signal disturbances. These disturbances can be caused by even a small change in the automatic excitation control (AEC) reference voltage, which results in a constant increase in rotor oscillations.

This is achieved by modulating the AEC so that the electric torque components develop in phase with the rotor speed deviations. Thus, the PSS contributes to the stability augmentation of power systems under weak signal conditions.

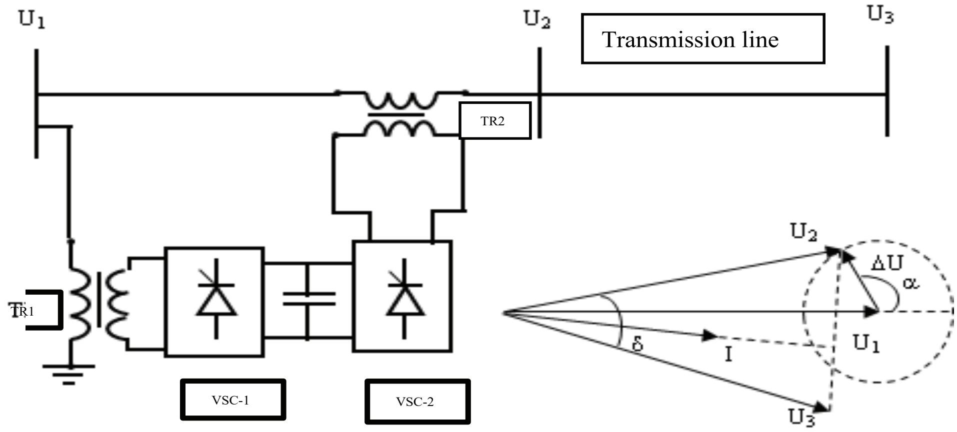

Fig. 1. The model of the UPFC system for damping of power system oscillations. TR1 – Transformer 1; TR2 – Transformer 2; VSC-1 – Voltage Source Converter-1; VSC-2 – Voltage Source Converter-2.

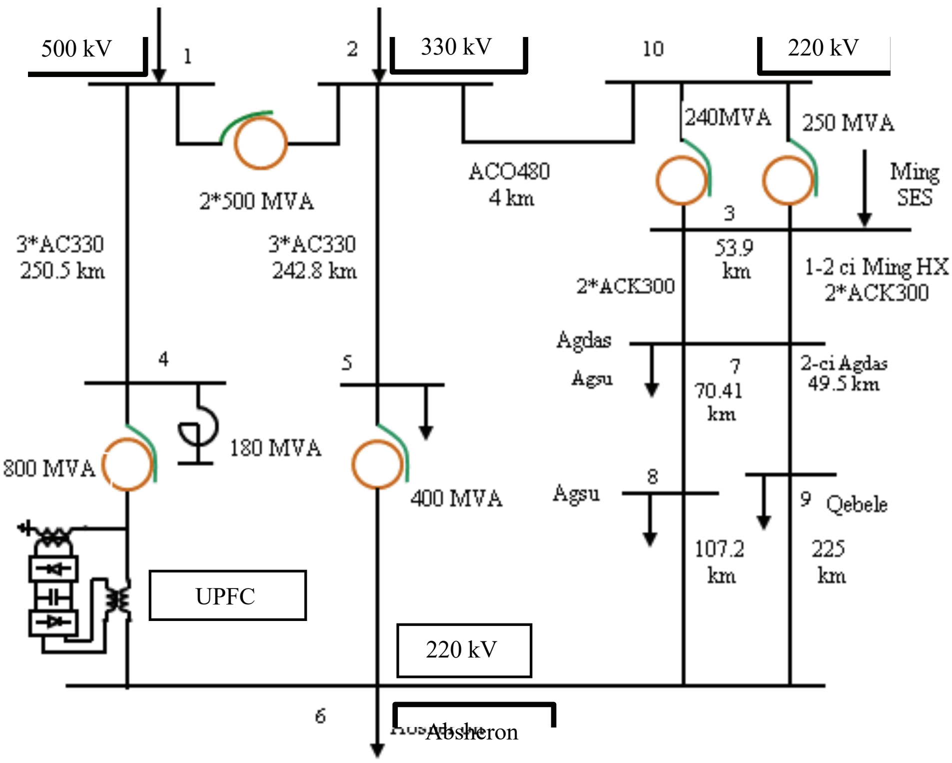

Fig.2. Equivalent circuit of the 220-330-500 kV section.

TABLE. Calculation Results for Power Flows with and without the UPFC

Branch 4–6	Active power flows in overhead line, MW			Active power loss in overhead line, MW				δ_6, degree
	P_{500}	P_{330}	P_{220}	ΔP_{sum}	ΔP_{500}	ΔP_{330}	ΔP_{220}	
With UPFC	971.4	403.1	433.0	57.81	30.7	12.3	14.4	–21.09
Without UPFC	888.3	449.0	482.0	69.27	30.5	17.6	21.2	–25.95

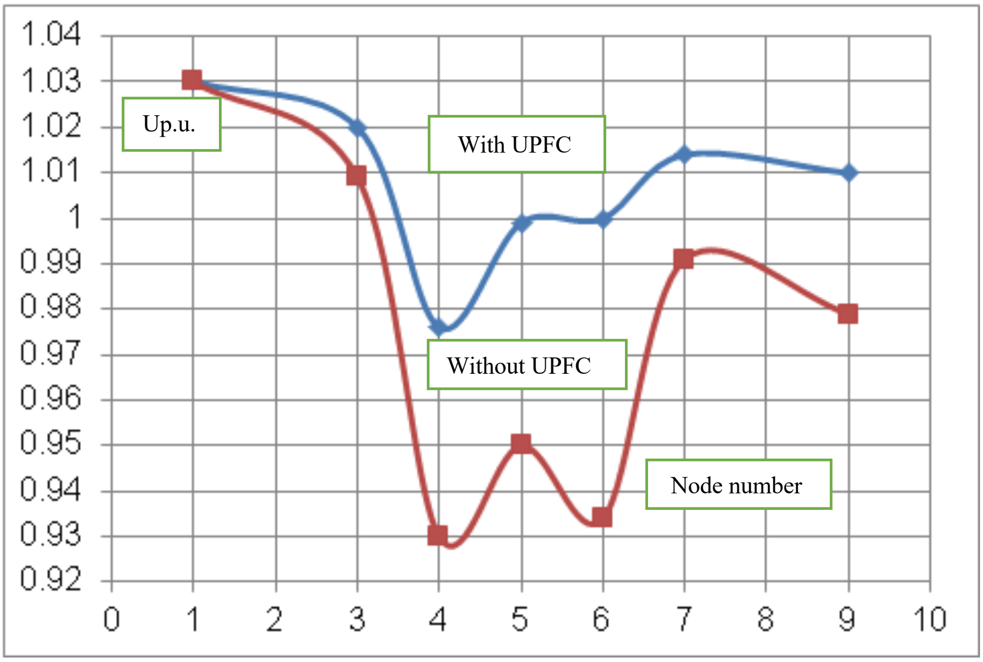

Fig. 3. Voltage profile by node.

Interconnected power systems are prone to generator rotor instability, especially when disparate groups of machines are connected to the system through power lines with UHV overhead lines. Oscillations between zone sections pose the greatest threat to widespread accidents leading to significant power outages.

The rotor instability phenomena can be studied by considering two different types of disturbances: weak-signal and transient ones.

The study of stability with a weak signal disturbance considers the electrical network to be under "normal" operating conditions, whereas the study on stability during transients examines the ability of the system to remain stable under large disturbances (e.g., transmission line failures). While many different features of the electrical network affect rotor stability (e.g., transmission line overloading, power system stabilizer (PSS) settings, etc.), the WADC architecture introduces sufficient torque to suppress the negative effects of resonant systems.

The static VAR compensator (SVC) is one of the FACTS shunting devices that augments network stability by limiting low-frequency oscillations, and others. The PSS also effective in damping of oscillations.

The STATCOM has an output feedback controller, and the PSS has a PI controller. These STATCOM and PSS devices are used together to improve the damping of power system oscillation.

V. Power System Stabilizers (PSS)

Excitation systems with a high gain factor and short response time greatly augment transient stability but can also reduce the stability of small signals (damping torque). Power system stabilizer control contributes to stability augmentation by damping generator rotor angle oscillations, which are in a wide range of frequencies in the power system. These vary from low-frequency cross-grid (usually 0.1–1.0 Hz), to local (usually 1–2 Hz) and in-plant (about 2–3 Hz) ones.

Weak links in line operations and large system loads can lead to poorly damped power flows between individual buses. PSS control can usually provide significant improvements in power flow damping between individual buses by applying stabilizers to most of the units that participate in power flows with power swings.

The PSS provides an excitation voltage modulation that dampens power and speed oscillations by means of conventional automatic voltage regulation (AVR) control. A study of its settings determines the optimal PSS settings based on the specific generator, automatic excitation control (AEC) settings, and system characteristics.

PSS is usually tested when the plant is put into operation. The testing condition for a PSS is that the output power has to be equal to the plants's base load or a value close to it. The testing of modern excitation systems is facilitated by the use of internal data logging and test signals.

Modern FACTS devices require state-of-the-art testing and validation approaches. These compensators can also be used to reduce voltage oscillations.

The problem of FACTS device placement is usually solved using heuristic optimization methods, which are diverse and constantly improving.

Short-term problems with voltage stability are usually due to the rapid response of voltage regulators (AVR of generators) and power electronic converters, such as those found in flexible AC transmission systems. In the case of voltage regulators, voltage instability is usually due to

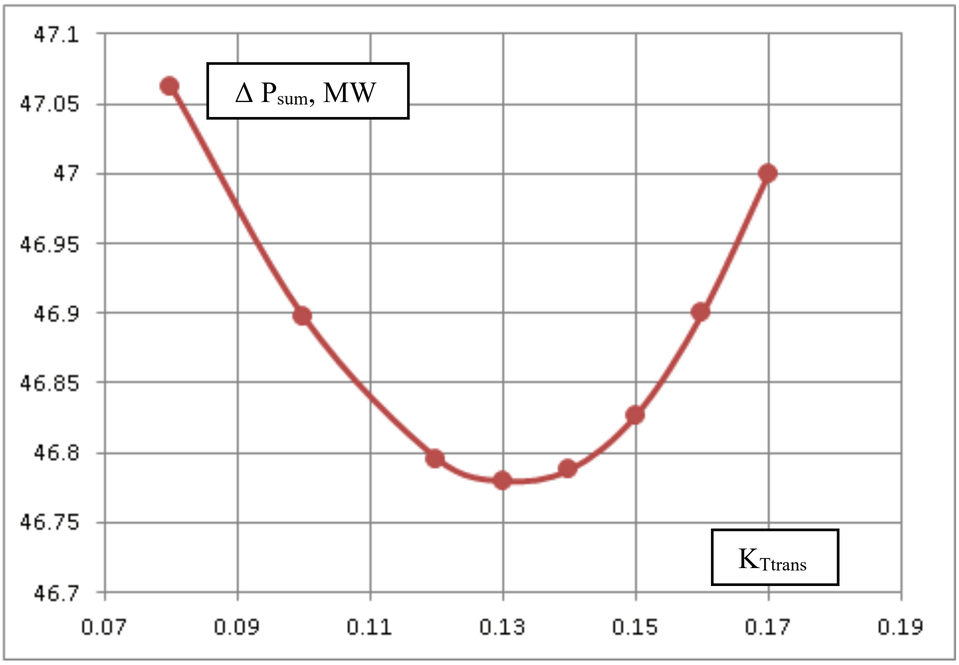

Fig. 4. Relationship between active power loss and the transverse component of the complex transformation ratio.

incorrect parametrization of the system controllers.

The equivalent circuit of the 220-330-500 kV section of Azerbaijan's power system combining two zones is shown in Fig. 2.

We consider the installation of a STATCOM (on the 220 kV buses of the Absheron substation with 220 kV, 330 kV, and 500 kV incoming transmission lines) and a UPFC (on the 500 kV line). The generation from power plants in the northwestern zone of Azerbaijan's power system is about 3 400 MW, that in the Absheron zone is about 3 000 MW.

VI. Comparative Results

The STATCOM and UPFC are installed at the end of the 500 kV overhead line on the side of ATr 800 MVA (500/220 kV), 220 kV Absheron substation.

We considered the active power consumption in the Absheron zone (at node 6), 1 600 MW, with active power consumption at 220 kV substations (Agdas, Agsu, Qebele) equal to 50 MW each (see Table).

The calculations were carried out using a software package developed by the Azerbaijan Scientific-Research Design-Prospecting Institute of Power Engineering. Modeling power flows relied on the appropriate mathematical models of FACTS.

Transfer capability of a transmission system is limited due to a variety of factors such as steady state stability limit, thermal limitation, transient stability limit, and system damping. The heterogeneity in the network circuit (Fig. 2) leads to overloading of 220 kV overhead lines and an increase in active power loss.

The active power flows at the 500 kV overhead line increase from 888.3 MW to 971.4 MW, and at 220 kV overhead lines, they decrease from 482 MW to 433 MW.

The voltage at the nodes of the circuit with and without the UPFC is shown in Fig. 3.

The use of UPFC reduces power losses by 11.46 MW.

According to calculation results, the installation of a STACOM on 220 kV buses in the Absheron power system (node 6), under normal operating conditions, reduces active power loss by more than 10 MW.

A STATCOM and a UPFC when installed simultaneously at node 6, under steady-state conditions, reduce loss of active power by more than 12 MW [12–15].

Active power loss as a function of the transverse component of the complex transformation ratio is shown in Fig. 4

In the case of power transmission of 1600 MW, the required reactive power generation from the Absheron power system is 320 MVAr.

The effect is achieved primarily due to the installation of a UPFC at node 6.

VII. Conclusion

1. The paper proposes augmenting the stability of Azerbaijan's power system by improving the damping of low-frequency oscillations with a unified power flow controller to be placed in the power system.
2. The findings suggest that the rational placement of UPFC:

- enhances the technical and economic performance of Azerbaijan's power system under all operating conditions;

- enables redistribution of active power flows over overhead lines in a heterogeneous 220 kV-330 kV-500 kV network: loading of 500 kV overhead lines by more than 100 MW and unloading of 220 kV overhead lines;
- reduces active power loss by more than 12 MW;
- improves voltage levels by up to 10% at power system nodes.

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