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PI & Fuzzy Logic Based Controllers STATCOM for Grid Connected Wind Generator

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Abstract-

When integrated to the power system, large wind farms pose stability and control issues. A thorough study is needed to identify the potential problems and to develop measures to mitigate them. Although integration of high levels of wind power into an existing transmission system does not require a major redesign, it necessitates additional control and compensating equipment to enable recovery from severe system disturbances. In this paper the STATCOM control scheme for the grid connected wind energy generation system for power quality improvement is simulated using MATLAB/SIMULINK in power systems block set. Fuzzy based controller is designed to improve the source current in STATCOM. A marked reduction in the Total Harmonic Distortion is observed in source current of Wind Power Generation System (WPGS) with the incorporation of Fuzzy controller.

Index Terms- Fuzzy Logic controller (FLC), Static Synchronous Compensator (STATCOM), Total Harmonic Distortion (THD), Wind Power Generation System (WPGS).

I. INTRODUCTION

Growing concern for limited fossil fuels reserves and CO_2 emission reduction stimulated development of the renewable energy sector. Especially, wind energy sector experienced huge thrust in recent years due to clean and economical energy generation. As an example, in European Union, in 2008 one third of the 23.85GW power generation was from wind turbine generators (WTG). As induction generator, which is the major source of reactive power, is connected with a wind turbine to generate electricity, the compensation of reactive power is necessary in order to maintain rated voltage in the network. Integration of wind energy into power systems on such a large scale is not straightforward. Power system and its operation was concerned with conventional power plants where synchronous generators were directly coupled to the grid. Wind power plants have different characteristics from the conventional ones. Thus, because of mismatch of their characteristics grid performance and stability is affected. Therefore, transmission system operators (TSO) were forced to impose New requirements for the connection of Wind Turbine Generators to the power network. This way, TSOs try to that all regulatory actions, which are needed for maintaining grid stability, are still performed on a satisfactory level, when renewable energy is introduced into the system. On the other hand certain devices like Flexible AC Transmission Systems (FACTS) were developed in order to dynamically control and enhance power system performance. Stability is the key aspect for introducing FACTS devices. Therefore one of the present day concerns is employment of FACTS devices for enhancing wind farm performance with respect to the grid codes and power system stability.

In this paper, we are presenting the work carried out in designing the Fuzzy logic controller for switching operation of STATCOM, a member of FACTS family. A simple control strategy of STATCOM is adopted where the measurement of rms current at the source terminal is needed. Then the performance of conventional PI controller and fuzzy logic controller (FLC) are investigated. Simulation results show that Total Harmonic Distortion (THD) in source current is drastically reduced fuzzy controller is included in the STATCOM control circuit. Simulation work has been done using MATLAB/SIMULINK software.

II. Static Synchronous Compensator (Statcom)

The STATCOM is a shunt-connected reactive-power compensation device that is capable of generating and/ or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals. Specifically, the STATCOM, which is a voltage-source converter which when fed from a given input of dc voltage, produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through a relatively small reactance (which is provided by either an interface reactor or the leakage inductance of a coupling transformer). The dc voltage is provided by an energy-storage capacitor.

A STATCOM can improve power-system Performance like:
1. The dynamic voltage control in transmission and distribution systems,
2. The power-oscillation damping in power-transmission systems,
3. The transient stability;
4. The voltage flicker control; and
5. The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

Furthermore, a STATCOM does the following:
1. It occupies a small footprint, for it replaces passive banks of circuit elements by compact electronic converters;
2. It offers modular, factory-built equipment, thereby reducing site work and Commissioning time; and
3. It uses encapsulated electronic converters, thereby minimizing its environmental impact.

A STATCOM is analogous to an ideal synchronous machine, which generates a balanced set of three sinusoidal voltages at the fundamental frequency with controllable amplitude and phase angle. This ideal machine has no inertia, is practically instantaneous, does not significantly alter the existing system impedance, and can internally generate reactive (both Capacitive and inductive) power.

Control Scheme:

The STATCOM is a static var generator whose output can be varied so as to maintain or control certain specific parameters of the electric power system. The STATCOM is a power electronic component that can be applied to the dynamic control of the reactive power and the grid voltage. The reactive output power of the compensator is varied to control the voltage at given transmission network terminals, thus maintaining the desired power flows during possible system disturbances and contingencies.

STATCOMs have the ability to address transient events at a faster rate and with better performance at lower voltages than a Static Var Compensator (SVC). The maximum compensation current in a STATCOM is independent of the system voltage. A STATCOM provides dynamic voltage control and power oscillation damping and improves the system's transient stability. By controlling the phase angle, the flow of current between the converter and the ac system are controlled. A STATCOM was chosen as a source for reactive power support because it has the ability to continuously vary its susceptance while reacting fast and providing voltage support at a local node. Fig. 1 shows the block diagram of the STATCOM controller.

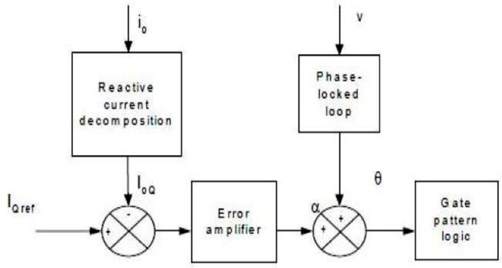

Fig. 1 Basic STATCOM control scheme

A STATCOM injects almost a sinusoidal current I_o of variable magnitude at a point of connection. The injected current is almost in quadrature with the line voltage V, thereby emulating an inductive or a capacitive reactance at the point of connection with the transmission line. The functionality of the STATCOM model is verified by regulating the reactive current flow through it this is useful to generate or absorb reactive power for regulating the line voltage of the bus where the STATCOM is connected.

Similarly when the system voltage is higher than the converter voltage, the system "sees" an inductive reactance connected at its terminal. Hence, the STATCOM "sees" the system as the capacitive reactance and the STATCOM is operating in an inductive mode. The current flows from the ac system to the STATCOM, resulting in the device absorbing reactive power. For an inductive operation the current lags the ac voltage by an angle of 90 degrees, by assuming that converter losses are neglected.

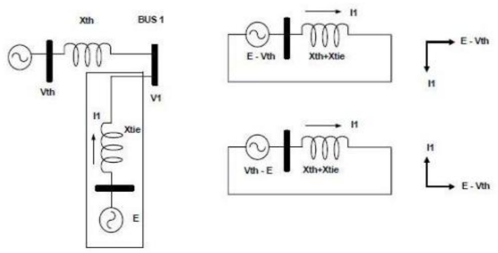

Fig. 2 A STATCOM operated in inductive and capacitive modes.

If the amplitude of the STATCOM output voltage and the ac system voltage are equal, the reactive current is zero and the STATCOM does not generate or absorb reactive power. Since the STATCOM is generating or absorbing only reactive power the output voltage of the converter, and the ac system voltage V are in phase when neglecting circuit losses. The ac current magnitude can be calculated by using the following equation

$$I_o = \frac{V_{out} - V}{X} \quad (1)$$

By assuming current flows from converter to the ac system. X is represented as the coupling transformer leakage reactance. The corresponding reactive power exchanged can be expressed as

$$Q = \frac{V_{out}^2 - V_{out} V \cos\alpha}{X} \quad (2)$$

Where angle α is the angle between the ac system bus voltage and the converter output voltage.

Iii. Wind Energy Generating System

The working principle of the wind turbine includes the following conversion processes: the rotor extracts the kinetic energy from the wind creating generator torque and the generator converts this torque into electricity and feeds it into the grid. Presently there are three main turbine types available. They are

- Squirrel-cage induction generator
- Doubly fed induction generator.
- Direct-drive synchronous generator.

The first one which is the simplest and oldest system consists of a conventional directly grid-coupled squirrel cage induction generator. The slip, and the resultant rotor speed of the Generator varies with the amount of power generated . The rotor speed variation is small, approximately 1% to 2%, and hence this is normally referred to as a constant speed turbine. The other two generating systems are variable –speed systems. In the doubly fed induction generator, a back to back voltage source converter feeds the three phase rotor winding, resulting that the mechanical and electrical rotor frequency are decoupled and the electrical stator and rotor frequency can match independently of the mechanical rotor speed. In the direct-drive synchronous generator, the generator is completely decoupled from the grid by power electronics, as a converter is connected to the stator winding and another converter is connected to the grid. Thus the total power delivered by the wind power is transmitted by an HVDC link.

In this paper, the configuration of wind generator is based on constant speed topologies with pitch control turbine. The induction generator is used in the proposed scheme because of its simplicity, it does not require a separate field circuit, it can accept constant and variable loads, and has natural protection against short circuit. The available power of wind energy system is given by the equation,

$$P_{wind} = \frac{1}{2}\rho A v_{wind}^3 \quad (3)$$

Where ρ (kg/m^3) is the air density, A (m^2) is the area swept out by turbine blade, v_{wind} is the wind speed in m/s. It is not possible to extract all kinetic energy of wind, thus it extracts a fraction of power in wind, called power coefficient C_p of the wind turbine, and is given by the following equation

$$P_{mech} = C_p P_{wind} \quad (4)$$

where C_p is the power coefficient, depends on type and operating condition of wind turbine. This coefficient can be expressed as a function of tip speed ratio and pitch angle. The mechanical power produced by wind turbine is given by the following equation

$$P_{mech} = \frac{1}{2}\pi\rho R^2 V_{wind}^3 C_p \quad (5)$$

Iv. Test System Model

The STATCOM based current control voltage source inverter injects the current into the grid in such a way that the harmonics are reduced in source current and their phase-angle with respect to source voltage has a desired value. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. To accomplish these goals, the grid voltages are sensed and are synchronized in generating the current command for the inverter. The proposed grid connected system is implemented for power quality improvement at point of common coupling (PCC), as shown in Fig. 3.

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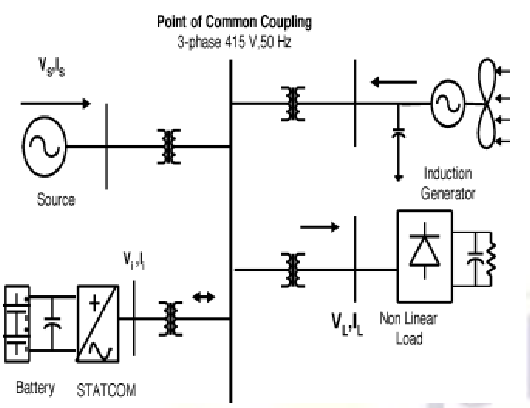


Fig. 3 Grid connected system for power quality improvement

V. Modelling Of Statcom

(a) Using conventional PI Voltage Regulator

The STATCOM control block diagram is shown in Fig. 4. The voltage regulator is of proportional plus integral type.

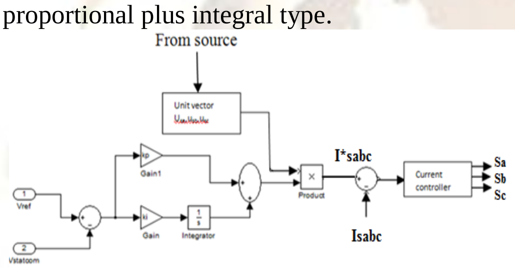


Fig. 4 STATCOM model with PI – Voltage Regulator block diagram

(b) Using FLC Voltage Regulator with FLC Bang-Bang controller

FLC voltage regulator is fed by one input that is voltage error (Ve). This gives the appropriate Reactive source current (I_s), which is required to the system. It is shown in Fig. 5.

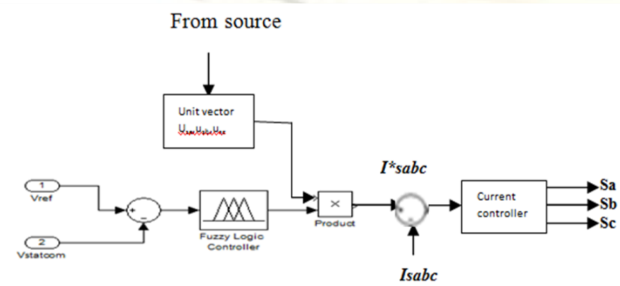


Fig. 5 STATCOM model with FLC- Voltage Regulator block diagram

VI. Control Circuit

The control scheme approach is based on injecting the currents into the grid using "bang-bang controller". The controller uses a hysteresis current controlled technique. Using such technique, the controller keeps the control system variable between boundaries of hysteresis area and gives correct switching signals for STATCOM operation. The control system scheme for generating the switching signals to the STATCOM is shown in Fig. 4 and Fig. 5. The control algorithm needs the measurements of several variables such as three-phase source current, DC voltage, inverter current with the help of sensor. The current control block receives an input of reference current and actual current are subtracted so as to activate the operation of STATCOM in current control mode.

In three-phase balance system, the RMS voltage source amplitude is calculated at the sampling frequency from the source phase voltage (V_{sa} ,V_{sb} ,V_{sc}) and is expressed, as sample template V_{sm}, sampled peak voltage, as in (6).

$$V_{sm}= \{\tfrac{2}{3}(V_{sa}^2 + V_{sb}^2 + V_{sc}^2)\}^{1/2} \qquad (6)$$

The in-phase unit vectors are obtained from AC source—phase voltage and the RMS value of unit vector u_{sa}, u_{sb}, u_{sc} as shown in (7).

$$u_{sa}=\frac{V_{sa}}{V_{sm}} \;;\; u_{sb}=\frac{V_{sb}}{V_{sm}} \;;\; u_{sc}=\frac{V_{sc}}{V_{sm}} \qquad (7)$$

The in-phase generated reference currents are derived using in-phase unit voltage template as, in (8)

$$i_{sa}^*=I.i_{sa} \;;\; i_{sb}^*=I.i_{sb} \;;\; i_{sc}^*=I.i_{sc} \qquad (8)$$

Where I is proportional to magnitude of filtered source voltage for respective phases. This ensures that the source current is controlled to be sinusoidal. The unit vectors implement the important function in the grid connection for the synchronization for STATCOM. This method is simple, robust and favorable as compared with other methods.

Bang-Bang Current Controller:

Bang-Bang current controller is implemented in the current control scheme. The reference current is generated as in (5) and actual current are detected by current sensors and are subtracted for obtaining a current error for a hysteresis based bang-bang controller. Thus the ON/OFF switching signals for IGBT of STATCOM are derived from hysteresis controller.

The switching function S_a for phase 'a' is expressed as equation (9).

$$i_{sa} < (i_{sa}^* - HB) \rightarrow S_a = 0$$
$$> (i_{sa}^* - HB) \rightarrow S_a = 1 \qquad (9)$$

Where HB is a hysteresis current-band, similarly the switching function can be derived for phases "b" and "c".

The control scheme is simulated using

SIMULINK in power system block set. The system parameter for given system is given Table I. The system performance under dynamic condition is also presented.

TABLE I
SYSTEM PARAMETERS

S. No	Parameters	Ratings
1.	Grid Voltage	3-Phase, 415V,50Hz
2.	Induction motor/generator	3.5KVA, 415V,50Hz,P=4, Speed=1440rpm,Rr=0.1Ω, Rs=0.15Ω,Ls=Lr=0.06H
3.	Line series Inductance	0.05mH
4.	Inverter Parameters	DC Link Voltage=800V,DC Link Capacitance=100μF, Switching Frequency=2kHz
5.	IGBT rating	Collector Voltage=1000V, Forward Current=50A,Gate Voltage=20V,Power Dissipation=310w
6.	Load Parameter	Non-Linear Load=25kw

Vii. Fuzzy Control

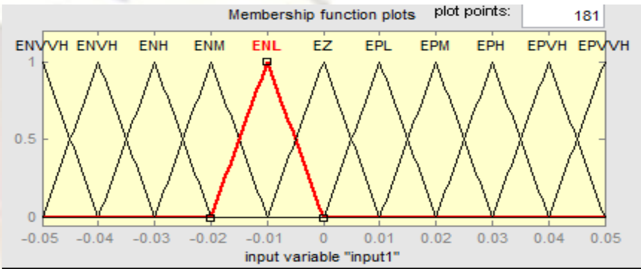
Fuzzy logic controller, approaching the human reasoning that makes use of the tolerance, uncertainty, imprecision and fuzziness in the decision-making process, manages to offer a very satisfactory performance, without the need of a detailed mathematical model of the system, just by incorporating the expert's knowledge into fuzzy rules. In addition, it has inherent abilities to deal with imprecise or noisy data; thus, it is able to extend its control capability even to those operating conditions where linear control techniques fail (i.e., large parameter variations).

FLC voltage regulator is fed by one input that is voltage error (Ve). The rules for the proposed FLC voltage controller are:

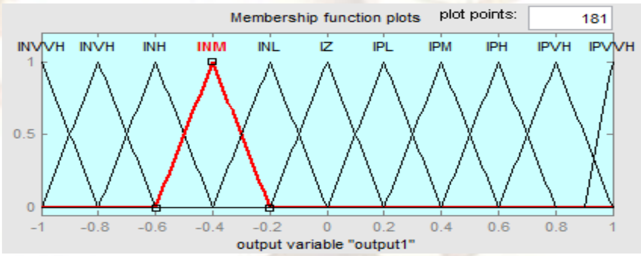
i) If 'Ve' is 'ENVVH' Then 'I' is 'INVVH'
ii) If 'Ve' is 'ENVH' Then 'I' is 'INVH'
iii) If 'Ve' is 'ENH' Then 'I' is 'INH'
iv) If 'Ve' is 'ENM' Then 'I' is 'INM'
v) If 'Ve' is 'ENL' Then 'I' is 'INL'
vi) If 'Ve' is 'EZ' Then 'I' is 'IZ'
vii) If 'Ve' is 'EPL' Then 'I' is 'IPL'
viii) If 'Ve' is 'EPM' Then 'I' is 'IPM'
ix) If 'Ve' is 'EPH' Then 'I' is 'IPH'
x) If 'Ve' is 'EPVH' Then 'I' is 'IPVH'
xi) If 'Ve' is 'EPVVH' Then 'I' is 'IPVVH'

This paper focuses on fuzzy logic control based on mamdani's system. This system has four main parts. First, using input membership functions, inputs are fuzzified, then based on rule bases and inference system, outputs are produced and finally the fuzzy outputs are defuzzified and applied to the main control system. Error of inputs from is chosen as input.

Fig. 6 shows input and output membership functions. To avoid miscalculations due to fluctuations in wind speed and the effects of noise on data, triangular membership functions are chosen to have smooth and constant region in the main points.



Input membership function



Output membership function

Fig. 6 Input and output membership functions of FLC voltage regulator

VIII Simulation Results

The wind energy generating system is connected with grid having the nonlinear load. It is observed that the source current on the grid is affected due to the effects of nonlinear load and wind generator, thus purity of waveform may be lost on both sides in the system. The three phase injected current into the grid from STATCOM will cancel out the distortion caused by the non-linear load and wind generator. Fig. 7 shows the source current waveform of the test system without STATCOM and the Fig. 8 shows the corresponding FFT analysis waveform. From FFT analysis, it is observed that the Total Harmonic Distortion (THD) of the source current waveform of the test system without STATCOM is 26.92%.

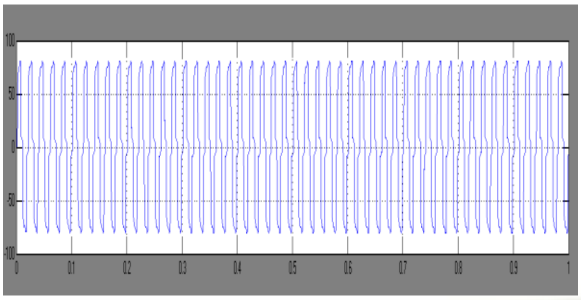


Fig. 7 Source current waveform of the test system (without STATCOM)

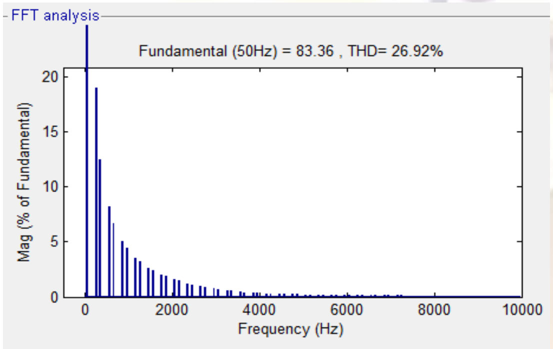


Fig. 8 FFT analysis of source current waveform of the test system (without STATCOM)

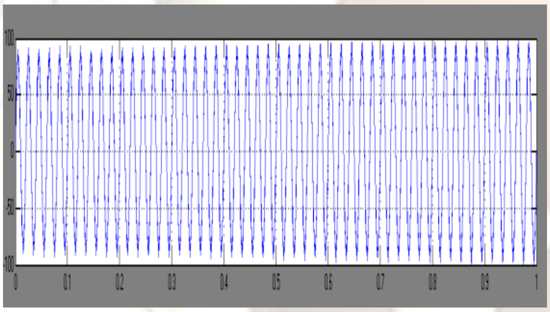


Fig. 9 Source current waveform of the test system with PI controller based STATCOM

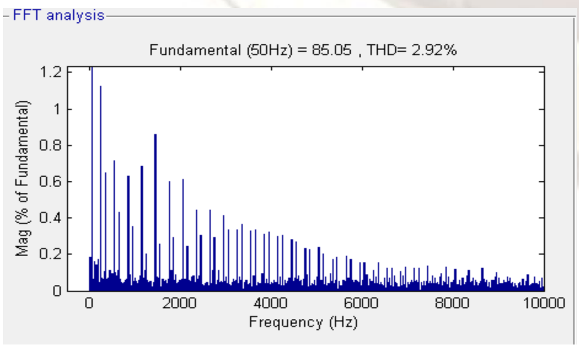


Fig. 10 FFT analysis source current waveform of the test system with PI controller based STATCOM

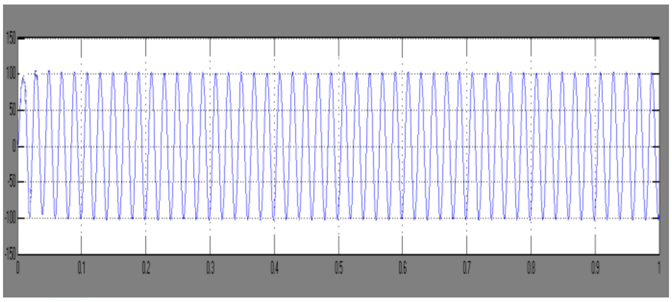


Fig. 11 Source current waveform of the test system with FLC based STATCOM

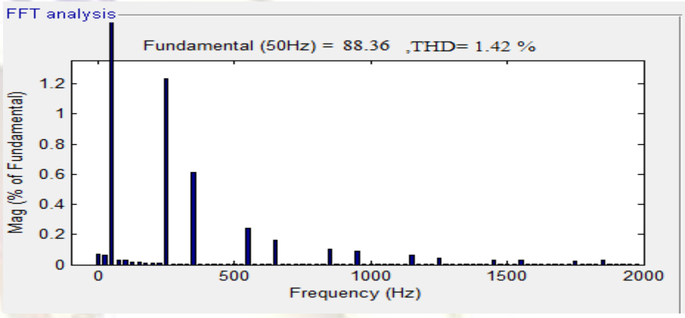


Fig. 12 FFT analysis of source current waveform of the test system with FLC based STATCOM

Fig. 9 shows the source current waveform of the test system with PI controller based STATCOM and the Fig. 10 shows the corresponding FFT analysis waveform. From FFT analysis, it is observed that the THD of the source current waveform of the test system with PI controller based STATCOM is 2.92 %.

Fig. 11 shows the source current waveform of the test system with FLC based STATCOM and the Fig. 12 shows the corresponding FFT analysis waveform. From FFT analysis, it is observed that the THD of the source current waveform of the test system with FLC based STATCOM is 1.42 %. Thus, it is observed that there is a further reduction in the THD value of the source current waveform.

IX Conclusion

In this paper fuzzy logic controller based STATCOM is presented for grid connected Wind Energy Generating System. The proposed FLC based STATCOM have improved the power quality of source current significantly by reducing the THD from 26.92% to1.42 %. It is clearly presented that STATCOM with FLC gives better performance than STATCOM with conventional PI controller.

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