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Review Article

A Comparative Study of AGC Performance on Interconnected Multisource Power System with Different Types of FACTS Controller: A Literature Review

Rani Thottungal[1], C. Udhayashankar[2], N. Mohana Sundaram[3]

[1]Professor, Department of ECE, Kumaraguru College of Technology, Coimbatore, India

[2]Associate Professor, Department of EEE, Kumaraguru College of Technology, Coimbatore, India

[3]Assistant Professor, Department of EEE, Kumaraguru College of Technology, Coimbatore, India

ABSTRACT

The Automatic Generation Control (AGC) of a power system plays an important role in delivering quality power to the consumers. Traditional PI and Intelligent Fuzzy Controller were commonly used with thermal generation for controlling the input flow to the prime movers. The recent advancements in solid-state devices and its applications have increased the power transmission efficiency of the system but with simultaneous generation of power quality issues like harmonics, poor voltage profile etc. In this paper, an effect is made to analyze the effect of various FACTS devices on aiding AGC in multiple sources fed the deregulated power system. The focus of the

Corresponding Author: Rani Thottunga < ranithottungal@yahoo.com >

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study is on the point of maintaining constant voltage and frequency with minimal total harmonic distortion.

Keywords: Automatic Generation Control, Deregulated, Flexible AC Transmission System, Thyristor Controlled Switching Capacitor, Unified Power Flow Controller

INTRODUCTION

In a traditional power system, generation, transmission, and distribution were controlled in one center and it was easy to maintain frequency by forecasting the load demand and generation. But by deregulation of the power system, different players arrived in the market and hence coordination and maintenance of grid frequency have become a challenge. The players are known as (1) Generation Companies (GenCos) (2) Transmission Companies (TransCos) and (3) Distribution Companies (DisCos). All these works on the objective function of profit maximization and there are independent players while one is dependent on one another. Regulating power quality poses a challenge to the regulating board due to the diverse control.

The industry is a complex and competitive market, where national strategies, policies, and macroeconomic developments play an important role. Since private investors can also enter the market, the objective function now includes (1) cost reduction (2) fuel availability and (3) development of new technologies.

The electrical energy produced by nuclear power station at a specified location and hydropower plant/thermal power plant at remote areas are the players in the conventional power generation market. With the advancements in the use of renewable sources like wind, solar, etc., even desert and offshore farms are pooled together with the breakthrough of power electronics technologies. Since all generated power is pooled area wise, any minor deviation in system frequency or scheduled tie-line power exchange to other areas can lead to outrages if not controlled. Hence, control strategies are needed for improving stability margin and overall power system reliability (Roy *et al.,* 2005 & Asia Pacific Energy Research Centre Institute of Energy Economics, 2000). These mismatches can be controlled by Automatic Generation Control. Automatic generation control (AGC) plays a major role in maintaining the quality of power generated, transmitted and distributed with reference to (1) frequency and (2) interchange of tie-line power among the control areas and generating units

Grid Stability

The energy produced should be able to reach the market at the right time in the right amount and quality, with a very competitive market price. This is carried out by the TransCos in a deregulated environment. They transport the high voltage over a long distance and has the responsibility of transmitting quality power and maintaining the balance between energy production and consumption at all times. Grid stability is always a concern for system operating securely and power system frequency is one of the vital parameters for maintaining grid stability. Any deviation in the frequency is to be brought into the nominal value within allowable range under any disturbances, as the stable frequency is necessary to keep generators and loads stable and safe. System frequency is generally controlled by (1) Primary Frequency Control: regulates the frequency of the system in a dynamic process and (2) Secondary Frequency Control: regulates the system frequency by load shedding of units participating in the system (Roy *et al.,* 2005 & Asia Pacific Energy Research Centre Institute of Energy Economics, 2000). This is achieved by sub-division of large areas into smaller areas based on the principle of coherency with an independent controller for interconnection between them. Each area will meet its own demands and scheduled interchange of power. Any mismatch between the supply and demand can be observed by frequency deviation. A sever deviation will imbalance the system stability of the operating system which can't be done by the conventional transient stability or voltage stability studies. To maintain the grid stability frequency, power interchange with neighboring control areas are to be maintained at the scheduled values.

Interconnected Power System

The smaller coherency area is connected by tie-line, for contractual energy exchange between areas and to provide inter-area assistance during abnormal operation. The advantages of the interconnected power system are:

- Provides a more efficient bulk transfer of power.
- It is possible to select the cheapest generation available.
- Transmission circuits are more reliable than individual generating unit.
- Surplus generation capacity in an area can be exported to cover up the shortfall in another area.
- With interconnection instead of controlling individual frequency response, the control needs to match the highest of the individual system requirement to cover the largest potential loss of power rather than the sum of them (Mukta, 2013).

In India, the four grids North, West, East, and South-East are operating synchronously with AC link. The fifth grid Southern grid is connected to East and West by HVDC link. All the five regional grids are further divided into state grids with their own respective control areas interconnected with AC links (Arya *et al*., 2012).

There are different methods of AGC controller, the latest being the use of Power Electronics technology. The pre-post method is using HVDC link.

I. High voltage direct current transmission

Even though High Voltage Alternating Current (HVAC) transmission have less loss in long-distance transmission, the problem of both sending end and receiving end operating at different frequency overshadows its advantages with respect to the asynchronous connection. The asynchronous interconnection can be done with the help of the HVDC link.

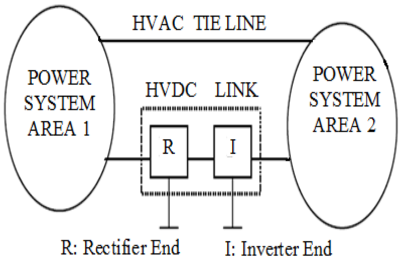

Fig. 1. Two area power system with parallel HVAC / HVDC Links

Figure 1 shows the HVDC link with conventional HVAC transmission. The advocacy for HVDC links is clear from the graph of investment cost and distance for transmission. It is obvious from Figure 2 that after a certain distance HVDC transmission is more effective. Also, in the HVDC system, there are no reactive power losses and stable operation can be achieved even at low power flow.

Still, there are some notable disadvantages in HVDC transmission viz:

- Additional filters for absorbing the harmonics are needed.
- Absences of reactive power which is required for normal operation at receiving end.
- Chances of sub-synchronous oscillation leading to instability of the grid.
- Cost of converter station is higher with respect to AC sub-station.

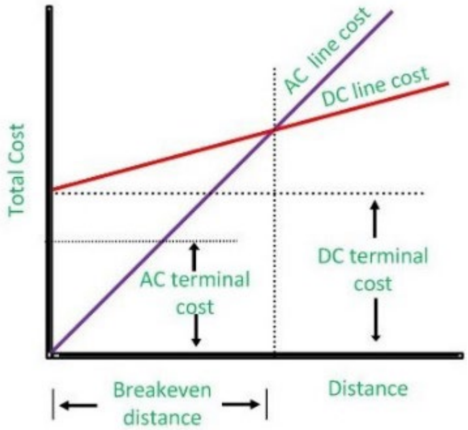

Fig. 2. Investment Cost *versus* Distance

With the use of HVDC link along with AC link i.e., combination of AC/DC system, the interconnected system becomes more stable due to the following facts: (1) HVDC can damp oscillation by its fast controller and (2) Weak AC connection can be allowed to exchange increased power between the interconnected area supported with HVDC control.

Knowing the advantages of using the technology of power electronics for the increased power transmission, the research is now focused towards the use of solid state devices in the form of FACTS devices.

II. FACTS Devices

In the present scenario of the restructured power system, flexibility in transmission line capacity is of great concern. Expanding the existing system is one solution but the main research is on increasing the utilization of the existing system by installing new technologies and devices. One of the latest technology in use is to improve the line impedance and to interchange the line impedance matrix of the transmission system. This can be achieved by shunting the passive elements like Capacitors or Inductors into the transmission line without shutting down the power transmission. This can be achieved by using solid state switches with fewer power losses. This hardware set up is called Flexible AC Transmission systems (FACTS) Devices.

The FACTS devices can control the power flow in loaded lines by increasing/decreasing loadability, low system loss, improved stability of the network, at a reduced cost of production. A number of FACTS controllers are proposed (Narain and Gyugyi, 2000 & Hingorani, 1991 & Hingorani, 1993 & Hingorani, 1988 & Mathur and Varma, 2002 & Song and Johns, 1999) and implemented essentially due to two reasons. Firstly, the recent development in cost-effective high power electronics and secondly, increased demand for power and advancement in renewable energy production combined with deregulation of the power industry. Commercial pressures on obtaining greater returns from existing assets suggest an increasingly important role for dynamic network management using FACTS device.

First Generation of Facts Devices

1. Static VAR Compensator (SVC)

2. Thyristor-Controlled Series Capacitor (TCSC)
3. Thyristor-Controlled Phase Shifter (TCPS)

Second Generation of Facts Devices

1. Static Compensator (STATCOM)
2. Static Synchronous Series Compensator (SSSC)
3. Unified Power Flow Controller (UPFC).
4.

III. Stability control using Static synchronous series capacitor (SSSC)

A study of the stability improvement and power oscillation damping using synchronous compensators SSSC is done in (Shankar *et al*., 2015). Complete simulation is done to confirm that voltage and power oscillation can be damped using SSSC with PI controller. Rani Thottungal et.al, have studied the stability performances using SSSC under various fault conditions. SSSC depends mainly on output amplitudes of voltage source converter made of several semiconductor switches. It produces a three-phase AC voltage with different magnitudes in quadrature with line current at the fundamental frequency with different phase angle.

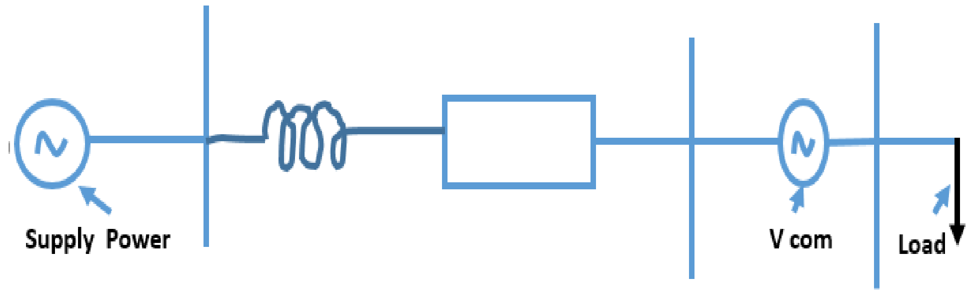

Fig. 3: Machine system with SSSC connected at the center

The maximum voltage $V_{maxp,q}$ injected by the SSSC can be rotated about an axis of the circle. The power flow can be increased or decreased depending upon the capacitive or inductive reactance. SSSC can operate under the following modes:

Capacitive Mode: The line current leads the injected voltage by 90° which will reduce the total transmission reactance

Inductive Mode: The line current lags the injected voltage by 90° which will increase the total transmission reactance

Using SSSC the generation and absorption of reactive power are kept under control which leads to working of power system successfully and efficiently with improved system performance.

The simulation was done on a Two Machine model with SSSC placed in the center. The results obtained are tabulated in Table I.

The ability of SSSC to damp the power oscillations to some extent is possible because it injects voltages with the transmission line serially and is independent of line current magnitude.

Table 1: simulation results of two machine model with sssc (for single phase fault)

Parameter	Without SSSC	With SSSC
Active Power	15 sec	8 sec
Reactive Power	12 sec, +ve oscillations	7 sec
Line Power stability	20 sec, -ve oscillations	17 sec, fewer oscillations
The voltage at Bus 2	8 sec with some oscillations	7 sec with fewer oscillations

IV. Stability Enhancement by installing UPFC

With SSSC injecting voltage in serially with a transmission line, a study was conducted to find the effects of UPFC. UPFC is a combination of shunt and series compensation which can either simultaneously or selectively control both active and reactive power and bus voltage.

The paper (Shankar *et al.*, 2012) reports how UPFC helps in improvement of stability under a fault condition. The optimal placement of UPFC has been evaluated using the Voltage Stability Index (Mukta, 2013 & Arya *et al.,* 2012 & Narain and Gyugyi, 2000 & Hingorani, 1991 & Hingorani, 1993). UPFC absorbs and injects active power with respect to the AC system. The DC link voltage V_{dc} remains constant and the real power demand by the series converter is supplied from the AC power system by the shunt converter through a common DC link. Shunt converter is able to generate or absorb controllable reactive power in both rectifier and inverter mode. The optimal position of UPFC was done using Genetic Algorithm. The fitness function is given below:

$$f(x) = A_1 \max(L_j) + A_2(Total\ Investment\ Cost) + A_3(Losses) \quad (1)$$

The cost function considered are given below:

$$C_{UPFC} = 0.0003S^2 - 0.2691S + 188.22\ US\$/kVAR \quad (2)$$

Where S is the operating range of UPFC in MVAR

$$S = |Q_2 - Q_1| \quad (3)$$

The objective was to place the FACTS devices in a way to increase voltage stability margin and to prevent transmission line congestion.

IEEE 5 bus system is taken as a test system and load flow analysis is done using the Newton Raphson method. 'L' index value was calculated for the buses and the results are tabulated in Table 2.

Table 2: Voltage Magnitude (VM) and Voltage Angle (VA) for a system with and without upfc

Without UPFC			**With UPFC**					
			Conventional NR-UPFC Algorithm			***Proposed GA Method***		
Bus No.	VM	VA	Bus No.	VM	VA	Bus No.	VM	VA
North	1.060	0.000	North	1.06	0	North	1.060	0.000
South	1.000	-2.061	South	1.00	-1.777	South	1.000	-2.177
Lake	0.987	-4.637	Lake	1.00	-6.020	Lake	0.997	-4.367
Main	0.984	-4.957	Lakefa	0.997	-2.510	Main	0.996	-4.59
Elm	0.972	-5.765	Main	0.992	-3.191	Elm	1.000	-7.346
	-	-	Elm	0.975	-4.970	Elmfa	1.020	-4.053

V. TCSC based damping controller

Thyristor Controlled Series Capacitor (TCSC) is placed in series with the Tie line (Morsali *et al.*, 2017). The active power transferred will increase as the apparent line impedance decreases.

$$P_{12} = \frac{|V_1||V_2|}{X_{12} - X_{TCSC}} \sin \delta_{12} \qquad (4)$$

If the series compensation ratio is defined as, $K_C = \frac{X_{TCSC}}{X_{12}}$

then,

$$P_{12} = \frac{|V_1||V_2|}{X_{12}} \sin \delta_{12} + \frac{K}{1 - K_C} \frac{|V_1||V_2|}{X_{12}} \sin \delta_{12} \qquad (5)$$

On linearization it is found that the first term is the power flow in tie line in absence of TCSC and second part contributes to the power flow by TCSC.

For a small perturbation the values δ_1^o, δ_2^o, and K_C^o are varied to δ_1, δ_2 and K_C and the change in tie line power when linearized around the operating point is given by,

$$\Delta P_{12} = \frac{|V_1||V_2|}{X_{12}} \cos\delta_{12}^o \sin \Delta\delta_{12} + \frac{1}{(1 - K_C^o)^2} \frac{|V_1||V_2|}{X_{12}} \sin \delta_{12}^o \,.\, \Delta K_C \qquad (6)$$

$$\Delta P_{12} = T_{12}\Delta\delta_{12} + C\Delta K_C \qquad (7)$$

Where $\quad C = \frac{1}{(1-K_C^o)^2} \frac{|V_1||V_2|}{X_{12}} \sin \delta_{12}^o \qquad (8)$

On expressing in Laplace Domain,

$$\Delta P_{12}(s) = \frac{2\pi T_{12}}{s} [\Delta F_1(s) - \Delta F_2(s)] + C\Delta K_C(s) \qquad (9)$$

$$\Delta P_{12}(s) = \Delta P_{12}^o(s) + \Delta P_{TCSC}(s) \qquad (10)$$

where

$$\Delta P_{TCSC}(s) = C\Delta K_C(s) \qquad (11)$$

represents the effect of TCSC on the tie line power flow exchange.

With dynamic control of ΔK_C, tie-line power flow exchange can be controlled continuously. In other words, the structure of TCSC can be considered as a frequency controller, where the frequency deviation in area 1 i.e. Δf, is used as an input control signal.

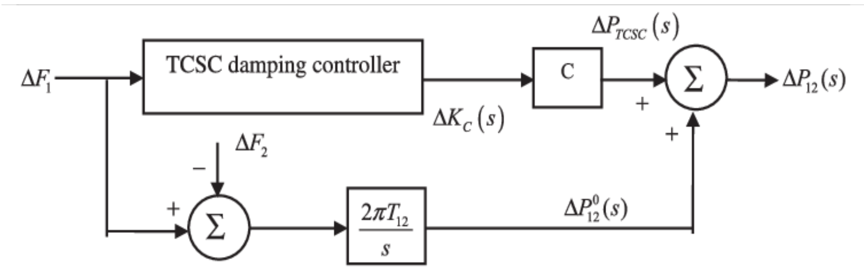

Fig. 4: Structure of TCSC as frequency controller

This transfer function of TCSC-based damping controller can be modified with phase lead-lag structure.

$$\Delta K_c(s) = \frac{K_{TCSC}}{1 + sT_{TCSC}} \frac{1 + sT_1}{1 + sT_2} \frac{1 + sT_3}{1 + sT_4} \Delta F_1(s)$$

where T_2 and T_4 are lag time constants and T_1 and T_3 are lead time constants.

Further in (Morsali *et al.*, 2017), Fractional Order PID (FOPID) is applied to design TCSC based damping controller. The Generation Rate Constraints (GRC) and Governor Dead Band (GDB) effects are also considered an Improved Particle Swarm Optimization (IPSO) technique is used.

In (Nandi *et al.*, 2017) instead of IPSO Algorithm, Quasi-Oppositional Harmony Search algorithm is used to find the adjustable gains of the FACTS devices. The algorithm is tested for a deregulated power system, by considering the following test system.

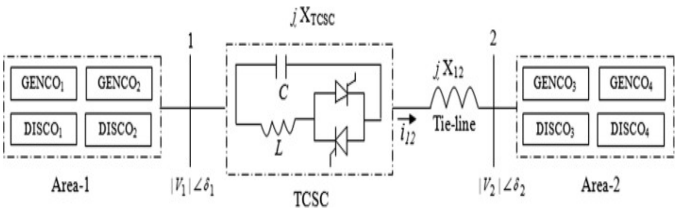

Fig. 5: Layout view of a studied test system

The simulation results show that the transient stability was improved and low-frequency oscillations were damped.

VI. Conclusion

In this paper, the regulation of the power system and its impacts are discussed in terms of grid stability. It is found that maintaining the voltage and frequency limit within the permissible limit is vital for achieving stability during system disturbances. The role of Automatic Generation Control (AGC) in the presence of HVDC link, various FACTS devices are studied and the observations are presented in this paper.

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