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POWER SYSTEM FACTS CONTROLLERS PERFORMANCE AND ANALYSIS FOR DAMPING OSCILLATIONS

G. MAHESH KUMAR[1], P.V. SATYARAMESH[2], K.S.R. ANJANEYULU[3] & P. SUJATHA[4]

[1]Assistant Divisional Engineer, TSSPDCL, Hyderabad, India

[2]Divisional Engineer, State Load Despatch Center Andhra Pradesh Transmission Corporation, Andhra Pradesh, India

[3,4]Professor, Department of EEE J.N.T.U, Ananthapuramu, Andhra Pradesh, India

ABSTRACT

In the recent past, the flexible ac transmission systems (FACTS) controllers plays vital role in power systems. In this paper, a novel non-linear switch for FACTS controlling manner for checking inter area fluctuations in the current systems is proposed. The FACTS regulating system have a series, shunt or blend of sequential shunt instruments that can be interfaced with the higher range of power system through dose buses. The adaptation of the system is used to improve FACTS efficiently damp low frequency inters area oscillations in the system. In this paper, we propose the system have controlling methodology that is based on concluding an equivalent lower affine non linear system for the networking from that the center machineries are separated based on active coherency. It is exhibited for if selected exact manner, proportions estimated from the machines subsystem is highly applicable inputs to the FACTS controllers to steady the power system. The accuracy and efficiency of the projected methodology on restraining inter area variations are real on the 68 bus system, 16 generator system of the countries such as England/New York network.

KEYWORDS: Dominant Machines, Phasor Measurement Unit, Flexible Ac Transmission Systems (FACTS)

INTRODUCTION

Flexible ac transmission systems (FACTS) controllers can prove to be a lot of dominant within the transmission to manage power flow actively around the set corridors and make sure security of voltage, as power electronics high voltage have a wider-range of operation and decrease the expenses of the controllers appreciably. FACTS controllers offer capable results to several of the firmness problems additionally to the current that happen at intervals the majority grid.

FACTS controllers are classified into three main categories: sequential devices like the static synchronous sequential compensator (SSSC), shunt machinery such as the electronic component such as Static Synchronous Compensator (STATCOM), and sequential shunt electronic devices like the unified power flow controller (UPFC).

An addition advantage of FACTS controllers positioned within the transmission mechanism for that will improved with effectively switch off the active power fluctuations that may degrade generators, increase wear and tear on network elements and finally destroyed, and increase linear line losses, additionally to steady-state keys such as management of voltage, current and power flow fluctuations. So, improving acceptable management approaches could be a condition before FACTS is absolutely highly improved in the management of system.

Many research scholars have studied applying FACTS, conversably UPFCs to dampish inter area fluctuations employing a variability of management approaches [1]–[10]. Due to eventualities such as sudden load faults or changes, inter area oscillations will occur in an exceedingly system. In [1]–[5], oscillation damping is predicated on a linear management methodology to the UPFC and facility, whereas alternative authors study Lyapunov Energy Functions and nonlinear management systems theory [6]–[10]. Typically, nonlinear approaches are a lot of active for giant agitations or once the facility system state waifs suggestively from the initial effective purpose.

UPFC MODEL

The proposed UPFC can be the highly effective and adaptable FACTS device. It improves a sequential branches associated through the DC capacitance and mix of a shunt as shown in Figure 1. By considering the shunt and sequential converters particularly, the models for the SSSC and STATCOM are merely extracted from the UPFC model. The consecutive articulate convertor injects a voltage with magnitude and purpose in time nonparallel with the conductor, consequently providing reactive and active power to the conductor. The shunt-distribution electrical converter supplies to energetic improved power strained due to sequentially bough and the wounded with may self-sufficiently offer reactive methodology compensation.

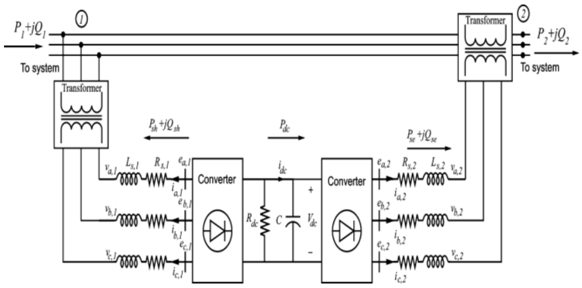

Figure 1: Diagram of Unified Power Flow Controller Diagram.

As given in (1)–(5), the UPFC methodology is given by [12] system. The figure 1 shows that the unified power flow controlling diagram. The supplied currents through the system $id1$ and $iq1$ are the dq systems of the magnitude shunt current manner. The currents $id2$ and $iq2$ are the dq equipments of the sequential current. The supplied voltages $V1\angle\theta1$ and $V2\angle\theta2$ are the transmitting and receiving the magnitudes of voltages and phase angles correspondingly without loss during the transmission of voltage and current. The UPFC is controlled by changing the magnitude and phase angles ($\alpha1, \alpha2$) and ($k1, k2$) improvingly expands of the division converter shunt and sequential output magnitude voltages ($e1, e2$), correspondingly.

The power balancing of the transmission and reception can be written as the equation as follows,

$$0 = V_1\left(\left(i_{d_1} - i_{d_2}\right)\cos\theta_1 + \left(i_{q_1} - i_{q_2}\right)\sin\theta_1\right) - V_1\sum_{j=1}^{n} V_i Y_{1j}\cos(\theta_1 - \theta_j - \varphi_{1j})\ldots \quad \ldots(1)$$

$$0 = V_1\left(\left(i_{d_1} - i_{d_2}\right)\sin\theta_1 - \left(i_{q_1} - i_{q_2}\right)\cos\theta_1\right) - V_1\sum_{j=1}^{n} V_i Y_{1j}\sin(\theta_1 - \theta_j - \varphi_{1j})\ldots\ldots \quad \ldots(2)$$

and at bus 2

$$0 = V_1((i_{d_2}\cos\theta_2 + i_{q_2}\sin\theta_2) - V_2\sum_{j=1}^{n} V_i Y_{2j}\cos(\theta_2 - \theta_j - \varphi_{2j})\ldots\ldots\ldots\ldots\ldots \quad \ldots(3)$$

$$0 = V_1((i_{d_2}\sin\theta_2 + i_{q_2}\cos\theta_2) - V_2\sum_{j=1}^{n} V_i Y_{2j}\cos(\theta_2 - \theta_j - \varphi_{2j})\ldots\ldots\ldots\ldots\ldots \quad \ldots.(4)$$

CONTROLLER DESIGN

There are three stages in the controller design.

A. LEVEL I

To select the preferred differences in the automatic mechanical powers drives required to make standard the efficient system is the objective of the major method of level 1. It is mainly such as the automatic mechanical powers drives, PMj are inputs into the methodology model, to make the improved mechanical power amount of quality. It is to be informed that it can be fairly progress within the power management; that can be given at finally for controlling methodology, the system requirement may not mandatory that the powers of generator automatic mechanical capacitance disagree.

The system model of (10) and (11) become $\dot{x} = F(x) + GU$…..(5) under this condition of assumption.

and $x = [\delta_1\omega_1\delta_2\omega_2 \ldots \ldots \delta_N\omega_N]$.

Meanwhile the proposed system obligatory that the system occurrences given back to steady stage manner quickly, a subset of (5) is $\dot{x_2} = f(x_1) + gu$………..(6)

Where $x_1 = [\delta_1\delta_2 \ldots . \delta_N]$ and $x_2 = [\omega_1\omega_2 \ldots . \omega_N]$, where $f(x_1) = [\begin{matrix} -\frac{1}{M_1}E_1\sum_{k=1}^{n}E_kY_{1k}\cos(\delta_1-\delta_k-\varphi_{1k}) \\ \vdots \\ -\frac{1}{M_N}E_N\sum_{k=1}^{n}E_kY_{Nk}\cos(\delta_N-\delta_k-\varphi_{Nk}) \end{matrix}]$

$$g = \begin{bmatrix} \frac{1}{M1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \frac{1}{M1} \end{bmatrix}$$

$$u = [Pm1\ Pm2 \ldots Pmn \quad]$$

Letting the variables such as x1s,x2s, and the mean of the steady-state structures of x1,x2 and u, then the error is calculated in terms of mean square error in occurrence of frequencies of rotor produces, correspondingly

E = a*x2-b*x2s

with

E^ = alpha{a*f(x)-b*f(x1s)-fx(gus)+fx(gud)}.

The performed mathematical equation can be reformed as,

u_d= $eps * g^{-1}$ [-a*f(x_1)+b*f(x_{1s})-$eps * gu_s$+H*Ke]

Where, K can be denoted as matrix of positive definition and then,

$$E^{\cdot} = -Ke$$

B. LEVEL II

In the level I, the required modifications within the generator's mechanical powers were found that stabilize the system. In Level II, these variations could be understood into managing given signals to the FACTS controller devices. Actually, the generator mechanical powers do not modify to the projected management. Consequently, victimization the anticipated active power variations, an ingenious management signal is given.

In the level I, the essential changes inside the generator's automatic required powers were found consequently that steady state of the system. In level II, these variations are ascertained into power management of signals to the FACTS controllers. Actually, the generator automatic mechanical powers do not alteration due to the successful system of power management. Consequently, due to the predictable active power differences, an efficient power system of management signal is given

$$\Delta u = u_{desired} - u_{actual}$$

where u_{actual} and $u_{desired}$are denoted as actual and desired parameters for the generator mechanical powers. This inconsistency is understood into the desired differences in the proposed FACTS can be given to the bus voltage angles and phase of power system is given by the controller, as exposed in (25) for further calculation, where

$$L = [l_{1,............l_N}]^T$$

$$\bar{\Delta} = [\Delta\delta_1, \ldots\ldots \Delta\delta_n]^T$$

The nonlinear power management criteria (25) is verified mathematically for $\bar{\Delta}$. Note the numerical analysis, if $N \neq n$, then the mathematical formulations methodology is an precise resolution and not quadrangle to (25) is not credible. In this case, the mathematical solutions are improved to find the best fit to $\bar{\Delta}$ which decreases the wrong estimation in (25). To calculate the necessary current inoculations $i *_{d1}, i *_{q1}, i *_{d2}, i *_{q2}$ from the equilibrium of power (6)–(9), these principles are then utilized.

C. LEVEL III

In this level III, the particular valuable current doses are understood into actual power management principles for the FACTS controllers. This technique is superior for the UPFC solely as before, noting that similar ways are often developed for the SSSC and STATCOM. A power analytical management supported [14] is employed to look for out the exacting power control inputs. The fundamental methodology of power management of prognostic management is to set up an asymptotically steady state controller such in an affine power system, the output y(t) tracks an united reference principle ω(t)in terms of a assumed presentation:

$$o\dot{x} = a * f\big(x(t)\big) + H * g\big(x(t)\big) * b * u(t)$$

$$o * y_i(t) = H * h_i(x(t)) \text{ i=1,….,m}$$

where m is the outputs number equivalent to the inputs number in $u(t)$. The receding prospect presentation directory is given as

$$J = \frac{1}{2}\int_0^T (\hat{y}(t+\tau) - \widehat{\omega}(l*t+l*\tau))d\tau \times (\hat{y}(l*t+l*\tau) - \widehat{\omega}(l*t+l*\tau))d\tau$$

where T is the logical duration. The exact control input $u(t)$ is given by the initial principle for $0 \leq l*\tau \leq l*$T and $u(t+\tau)$ of the best control input $\hat{u}(t+\tau)$ when τ =0.

The low of most favorable extrapolative organize is provided by

$$u(t) = -(L_g l_f^{p-1} h(x))^{-1}(KM_\rho + L_f^\rho h(x) - x * \omega^{(\rho)}(l*t)$$

whereρ is the relative score for the system outputs and L is the Lie resulting distinct by

$$L_{\mu}v = \frac{\partial v}{\partial x}\mu$$

The matrix K is provided by

$$M_{\rho} = \begin{bmatrix} h(x) - w(t) \\ L_f^1 h(x) \quad w^{[1]}(t) \\ \vdots \\ L_f^{\rho-1} h(x) - w^{[\rho-1]}(t) \end{bmatrix}.$$

.

The first rows of the matrix $\psi_{rr}^{-1}\psi_{\rho r}^{T}$ is the matrix K where

$$s_{rr} = \begin{bmatrix} s_{(a\rho+1,b\rho+1)} \cdots & s_{(a\rho+1,b\rho+r+1)} \\ s_{(a\rho,b\rho+1)} \cdots & s_{(a\rho+r+1,b\rho+r+1)} \end{bmatrix}$$

$$s_{\rho r} = \begin{bmatrix} s_{(1,\rho+1)} \cdots & s_{(1,\rho+r+1)} \\ s_{(\rho,\rho+1)} \cdots & s_{(\rho,\rho+r+1)} \end{bmatrix}$$

Where

$$s(_{i),j} = \frac{\overline{l*T}^{i+j-1}}{e(i-1)!(j-1)!(i+j-1)!}, \text{ i, j=1,....,} s\rho + sr + 1$$

And

$$\overline{sT} = diag\{sT, \ldots\ldots, sT\} \,\epsilon\, sR^{m\times m}$$

frequently to (1)–(5), conceited the control system of order to be $r = 0$, the comparative quantity for all of the outputs is $\rho = 1$, then the power control commandment for the UPFC becomes

$$u_1 = \frac{-3L1}{\omega_s v_{dc} T}\left(i_{d_1} - i_{d1}^*\right) + \frac{R_1}{V_{dc}} i_{d1} - \frac{L_1}{V_{dc}} i_{q1} + \frac{V_1 \cos\theta_1}{V_{dc}} + \frac{L_1}{\omega_s V_{dc}} \frac{d}{dt} i_{d1}^*$$

$$u_2 = \frac{-3L1}{\omega_s v_{dc} T}\left(i_{q1} - i_{q1}^*\right) + \frac{R_1}{V_{dc}} i_{q1} - \frac{L_1}{V_{dc}} i_{d1} + \frac{V_1 \sin\theta_1}{V_{dc}} + \frac{L_1}{\omega_s V_{dc}} \frac{d}{dt} i_{q1}^*$$

$$u_3 = \frac{-3L1}{\omega_s v_{dc} T}\left(i_{d_2} - i_{d2}^*\right) + \frac{R_1}{V_{dc}} i_{d2} - \frac{L_1}{V_{dc}} i_{q2} + \frac{V_2 \cos\theta_2}{V_{dc}} - + \frac{V_1 \cos\theta_1}{V_{dc}} \frac{L_2}{\omega_s V_{dc}} \frac{d}{dt} i_{d2}^*$$

$$u_4 = \frac{-3L_2}{\omega_s v_{dc} T}\left(i_{q2} - i_{q2}^*\right) + \frac{R_2}{V_{dc}} i_{q2} - \frac{L_2}{V_{dc}} i_{d2} + \frac{V_2 \sin\theta_2}{V_{dc}} - \frac{V_1 \sin\theta_1}{V_{dc}} + \frac{L_1}{\omega_s V_{dc}} \frac{d}{dt} i_{q1}^*$$

These contributions are then interpreted for the UPFC into the control inputs

$$k_1 = \sqrt{u_1^2 + u_2^2}$$

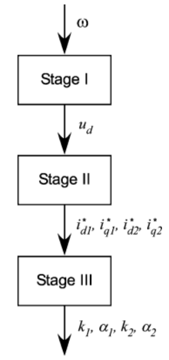

Figure 2: Three Stage Control Process.

$$\alpha_1 = \tan^{-1}\frac{u_2}{u_1}$$

$$k_2 = \sqrt{u_3^2 + u_4^2}$$

$$\alpha_2 = \tan^{-1}\frac{u_4}{u_3}$$

MEASUREMENTS FOR SELECTIVE FEEDBACK BASED ON DOMINANT MACHINES

In the previous section, the power system management technique is shown and it desires generator magnitude rotor dominant occurrences to be less priority. Though with actual current developments in Wide Area Frequency Measuring (FNET) it is going to be probably to supply to the stage controlling harmonized international dimensions in terms of its current and frequency, it is still improve to assume that each one magnitude of rotor generator frequencies are instantly offered. Though, it is precise to just accept that a set of the scale is available for feedback and also the states remainder are often assessed supported the offered dimensions. To get measurements from are those machines that management clear teams. For artful coherent teams within the literature [15]–[18], there are varied strategies. In [18], the coherency documentation methodology relies on mathematician elimination and modal analysis with full turning on the selected eigenvectors of the system to search out the reference generators and their cluster members. The selected eigenvectors are selected supported the deepest periodic modes of the system. A reduced order system is calculated that grabs the “slow” dynamics of the initial system, once the dominant machines are found. The outstanding unmeasured states of the system are often calculable supported the states that are restrained via singular perturbation [13] during this procedure. Let the remainder of the machines be numbered from letter+1 to N and also the leading machines be ordered from one to Q, then the deviations within the non-dominant machineries are often approached employing a zero-th order epitome.

In the above procedure, the power system management technique is shown and it wants generator rotor incidences to be performed. Thus with current developments in wide space frequency measuring (FNET) it is going to be apparently to provide harmonically global magnitudes, it's still impracticable to presume that each one rotor generator frequencies are instantly offered. Though, it is sensible to just accept that a set of the level is getable for feedback and also the states residue may be assessed supported the on the sufficient dimensions. To get dimensions from are those equipments that power system management clear teams. For artful logical teams within the literature [15]–[18], there are divergence strategies. In [18], the coherency documentation technique is predicated on Gaussian removal and modal investigation with full rotating on the chosen eigenvectors of the scheme to look for out the orientation generators and their come together members. The chosen eigenvectors are chosen supported the earnest periodical modes of the power system. A reduced order of mathematical system is estimated that observed the "slow" dynamics of the first system, once the leading machines are found. The outstanding unmeasured states of the system may be calculable supported the states so as to are reserved via remarkable perturbation [13] during this procedure. Let the remainder of the machines be numbered from alphabetic character+1 to N and also the leading machines be ordered from one to Q, then the deviations within the non-dominant machineries may be approached employing a zero-th order model by

$$\begin{bmatrix} X_{Q+1,Q+1} & \cdots & X_{Q+1,N} \\ \vdots & \ddots & \vdots \\ X_{N,Q+1} & \cdots & X_{N,N} \end{bmatrix} \begin{bmatrix} \Delta\delta_{Q+1} \\ \vdots \\ \Delta\delta_N \end{bmatrix}$$

$$\begin{bmatrix} \sum_{k=1}^{Q} X_{Q+1,k}\Delta\delta_k - \sum_{k=N+1}^{N+n} X_{Q+1,k}\Delta\delta_k \\ \vdots \\ \sum_{k=1}^{Q} X_{N,k}\Delta\delta_k - \sum_{k=N+1}^{N+n} X_{N,k}\Delta\delta_k \end{bmatrix}$$

Where

$$x_{i,j} = \frac{\mu_{ij}}{\mu_{ii}}$$

And

$$\mu_{ij} = -E_i E_j Y_{ij} \sin(\delta_i - \delta_j - \varphi_{ij}) \ \mathrm{i} \neq \mathrm{j}$$

$$\mu_{ii} = -\sum_{k\neq i}^{N+n} E_i E_j Y_{ij} \sin(\delta_i - \delta_j - \varphi_{ij}) \ \ \mathrm{i} = \mathrm{j}$$

Examine than once solely the leading machines are selected for the power system management action, solely the rows conventional to the leading machines are employed in (25) so dipping the order of the system. To determine the set of mathematical formulation is particular addition nearly square giving higher convergence, this is often helpful since the pseudo-inverse necessary.

EXAMPLE AND RESULTS

The management technique are going to be estimated using the complete tenth order model that contains rotor engine, an exciter/AVR, and governor dynamics, although the management has been progressed based on the conventional generator model. The model is provided within the explanation. The methodology is proposed to manage the power system for management is optimized on the 68 bus, 16 generators in the countries such as New York/New European nation check system. The coherent groupings and network knowledge are the identical as in [19]. With daring lines, the transmission tie lines are discovered. The reference five areas generators are G13, G14, G5, G15, and G1.

The power system management methodology are investigated based on the total tenth order model that includes rotary engine, governor dynamics, an exciter/AVR, although the power system management has been progressed utilization the traditional generator model. The model is provided within the Appendix. The projected power systems management is investigated on the sixty eight bus, sixteen generator New York/New England take a appear at system. The logical groupings and system information are the matching as in [19]. With bold transmission lines, the transmission tie lines are obvious. The reference 5 areas generators are G13, G14, G5, G15, and G1

Table 1: Facts Parameters

	R_1	L_1	R_2	L_2	R_p	C
UPFC	0.01	0.15	0.001	0.015	25	1400
STATCOMs	0.01	0.10	n/a	n/a	25	1200

Figure 3 demonstrate a separation matching originator makes the system fast with no FACTS controllers for the methodology scheme connected to Case 1). The information may not thus every equation is exposed for the sake of briefness. From four of the five logical areas, the selected generators are kept back. Note that the creator goes rough because of the load, but the proposed control can soothe the system and quickly alleviate the fluctuations.

The determined power injections of the UPFC are show in Figure 4. The sequential injection is discovered within the major graphical information and also the information matching shunt generation system is displayed in the given figure. Case 2 is compared to Case 3in figure 4. This sequential plan of active power injection for the planned power system management is incredibly unsure; so, the rating of the sequential electrical device and convertor could not have to be higher range of enormous. The sequential active power is associated to the DC link shunt active capacitance power

$$-P_{shunt} = P_{series} - \frac{V_{dc}^2}{R_{dc}}$$

Consequently P_{shunt} are opposing in division to P_{shunt} and can differ in absolute magnitude by the losses within the convertor. To boot, all through transients the dc connection condenser can release or charge active power. The shunt convertor vaccinates active power into the organization all through the accountability. Similar performance is showed by the STATCOMs as shown in Figure 8. Conjointly monitor that, the shunt active power absorbed is optimistic, so the steady-state the STATCOM will take up magnitude of active power and conjointly the figures state a positive value. The dc link condenser voltages are shown in figure 9. The UPFC and one in every of the STATCOMs involve a drop of roughly fifth whereas the second STATCOM experiences low rise in voltage. This may be sensible, it ought to be necessary to place in active power in some areas and absorb energetic power in dissimilar areas, as a result of to damp fluctuations.

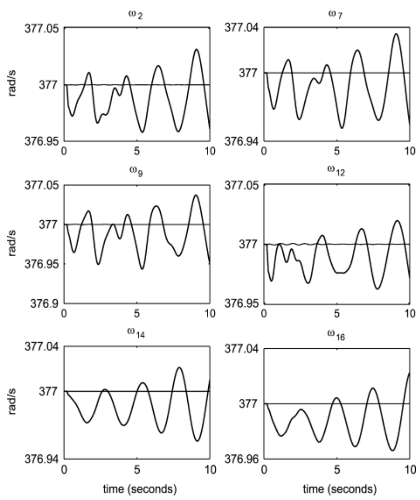

Figure 3: Generator Speeds for No Facts Controllers (Bold) and Case 1 (Thin)

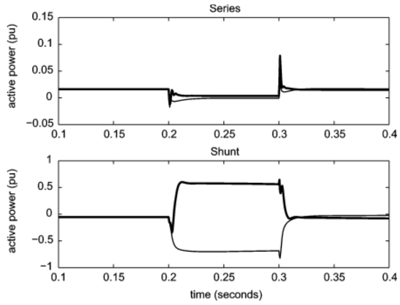

Figure 4: UPFC Injected Active Power

CONCLUSIONS

The multiple FACTS controllers are used for damping inter area oscillations, a 3 stage non-linear control system has been proposed in this paper. For damping inter area oscillations mistreatment multiple FACTS controllers, a three-stage nonlinear management theme has been planned. Based on dimensions from the dominant generators and estimating the rest of the states supported equivalent scale active power systems is shown to significantly reduce the number of necessary management. Because of the feedback knowledge for the power systems management, the method uses the generators' occasion. Any FACTS device which will switch its line bu phase angle(s) with the capability organization can use this power system management approach. The proposed methodology displays capable consequences for wide-area power systems management of power, supported the simulation results. There are quite a few issues that should be in use into deliberation but. During the power system management the considerable process loads for the controller which needs quick processors for time period performance. However, by raising the opinion method, reasonable logical groupings can lower the calculation time. Compassion between existing methodology and proposed methodology to scheme suspicions and topology changes also will be deliberated. Future work also will reflect about the consequence of your time latency and communication random noise within the deliberated states on the power management accurate and effectiveness.

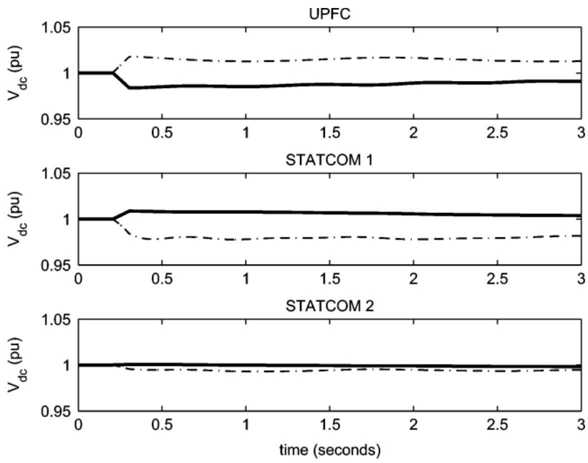

Figure 5: FACTS Vdc: Case 2 (Bold) and Case 3 (Dashed)

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