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Lyapunav Energy Function and Fuzzy Based Control of UPFC For Transient Stability Enhancement In Multimachine Power Systems

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Abstract

This paper presents the effect of Unified Power Flow Controller for stability improvement and damping the oscillations in multimachine system. It also provides the information about energy function whichis used to calculate the stability of the machine without any graphical information. A power system is subjected to both predictable and unpredictable disturbances which constantly change the systemoperating conditions. Therefore a decentralized self tuning control scheme for the stability enhancement of multimachine power system was developed. The results were tested with 9 bus, 3 generator system. The results arrived out of energy function method is interpreted using fuzzy logic.

Keywords: Stability Margin, UPFC, Energy Function.

Introduction

For economical and technological reasons, individual power systems are organized in the form of regional grid, so that each area is contractually tied to other areas in respect to certain generation and scheduling features. The synchronous machines of all interconnected areas must operate stably and in a synchronized manner. The disturbance caused by a short circuit in one area must be rapidly disconnected by circuit breaker openings before it can seriously affect adjoining areas.

Instability of the system affects voltage profile of the system, the quality of the supply and it leads to make the system unreliable. Therefore stability considerations have been recognized as an essential part of the power system planning for a very long time.In view of the rapid growth of the power system all over the world, the interconnection of power systems has become ‘must’. Interconnection can improve reliability through mutual aid in emergency situations. Interconnections can also lead to inter area oscillations that can ultimately lead to instability. Adequate system design and discrete supplementary controllers can achieve improvement in transient stability [1]. The emerging flexible AC transmission system (FACTS) controllers are considered to be suitable for this purpose due to their speed and flexibility. The Unified power flow controller (UPFC) is a voltage source converter based FACTS controller which injects series voltage and shunt current. Maximum improvement in transient stability can be achieved by maximizing the electrical power output of the generator with respect to the control ariables.[2,3].Transient stability evaluation using digital simulation requires solution of nonlinear differential algebraic equations over a time interval extending to several seconds. This is computationally burdensome, because for a given system configurations and loading conditions with a specified generation pattern the transient stability is also a function of the disturbance. Thus there is a need for fast method that leads to Extended Equal Area Criterion to determine the maximum rotor angle during the transient period. During the acceleration period the system acquires some transient energy with respect to post fault stable equilibrium point. The transient energy at the unstable equilibrium point is known as critical energy. For the system to be transiently stable the critical energy must be greater than or equal to the transient energy acquired during the acceleration period. The transient stabilitymargin is the difference between the critical energy and the transient enrgy acquired by the system during the acceleration period.To improve the stability margin the controller must be capable of either increasing the critical energy or reducing the acquired transient energy.This paper deals with improvement of stability margin incorporating UPFC using energy function method [4,5].

Flexible Ac Transmission System

The reactive shunt compensation is highly effective in maintaining the desired voltage profile along the transmission line interconnecting two buses of the ac system and providing support to the end voltage of radial lines in the face of increasing power demand.But it is also highly effective in controlling the actual transmitted power, at a defined transmission voltage is ultimately determined by the series line impedance and the angle between the end voltages of the line.Controllable series compensation is a corner stone of FACTS technology. Transient stability improvement by controlled series compensation is achieved by increasing the power transmission via increasing the transmission line voltage during the accelerating swing of the disturbed machine.The powerful capability of series line compensation to control the transmitted power can be utilized much more effectively to increase the transient stability limit and to provide power oscillation dampling [6,7]. FATS technology incorporates power electronic based system and other static equipment to enhance controllability and increase power system capability.

Types of FACTS controllers:
Series controllers
Shunt controllers
Combinedshunt-series controllers
Combined series –series controllers

UPFC is a combined shunt- series controllers, which takes power from the transmission line by means of shunt transformer and injects the reactive power through series transformer.Fig.1 shows the schematic diagram of UPFC.

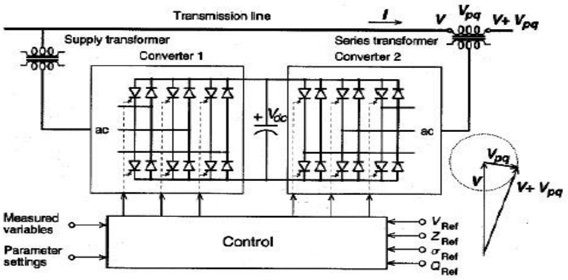

Figure 1: schematic diagram of UPFC.

Operation

UPFC consists of two voltage sourced back to back inverters. This arrangement is functioned as an ideal ac to ac power converters in which the real power can freely flow in either direction between the ac terminals of the two converters and each converter can independently generate or absorb reactive power at its own terminals. Converter 2 provides the main function of the UPFC by injecting voltage vpq with controllable magnitude vpq and phase angle rho in synchronous with the line via an insertion transformer. The injected voltage acts essentially as a synchronous ac voltage source[11]. The transmission line current flows through this voltage source resulting in real and reactive power exchange at theca terminal internally. The real power exchanged at the ac terminal internally is converted in to dc power which appears at the dc link as a positive or negative real power demand.

Control Structure

The UPFC control scheme is functionally divided in to internal control and converter control.

Internal control: The internal control operate two converters so as to produce the commanded series injected voltage and simultaneously draw the desired reactive shunt current. The internal control provide firing signals to the converter valves.

Series converter: It responds directly and independently to the demand for series voltage injection. Changes in series voltage vector vpq can therefore be affected instantaneously.

Shunt converter: it operates under a closed loop control structure whereby the shunt real and reactive power components controlled independently.the control loop for the shunt real power should ensure the required real power balance between the two converters.

Control Methods

1. In phase voltage control:

The voltage regulation is achieved with continuously varying in phase voltage injection.

Voltage Vpq= ±ΔV (ρ=0)

2. Shunt compensation control: In shunt compensation where Vpq =Vq is injected in quadrature with the line current I2. The injected series compensating voltage can be kept constant if desuired independent of line current variation.
3. Quadrature voltage control Phase angle regulation is achieved by Vpq=Vρ is injected with an angular relationship with respect to V that achieves the desired rho phase shift without any change in magnitude.

UPFC is one of the FACTS controller can control simultaneously or selectively voltage, impedance, phase angle of the transmission line which can ultimately control real and reactive power flows. The three control variables namely voltage magnitude (Vpq) injected by the booster transformer, voltage phase angle difference (ρ) and the existing transformer reactive current (Iq) can be regulated independently with in a region Γ defined by

Γ={ Vpq, ρ, Iq}
Vpq € { 0, Vpq max}
ρ € {0, 2Π }
Iq € {- Iqmax, Iqmax}

Multimachine System

Multimachine system without the reduction of the single equivalent analysis is preceded[9]. The steps for determining multimachine stability is as follows.

1. From the prefault load flow data voltage EK behind transient reactance for all generators was determined.i.e generator emf magnitude ek was assumed as constant during the study and initial rotor angle sk=ang(ek) . Also the prime mover input to the generator is noted.
2. The load flow network is augmented by the generator transient reactance. The network buses are shifted behind transient reactance.
3. Then ybus is calculated for various network conditions prefault during fault and post fault.
4. for faulted mode generators output are calculated from power angle equations and swing equations are solved.
5. the above steps are repeated for post fault mode.
6. stability of all generators are determined by s(t) plot.

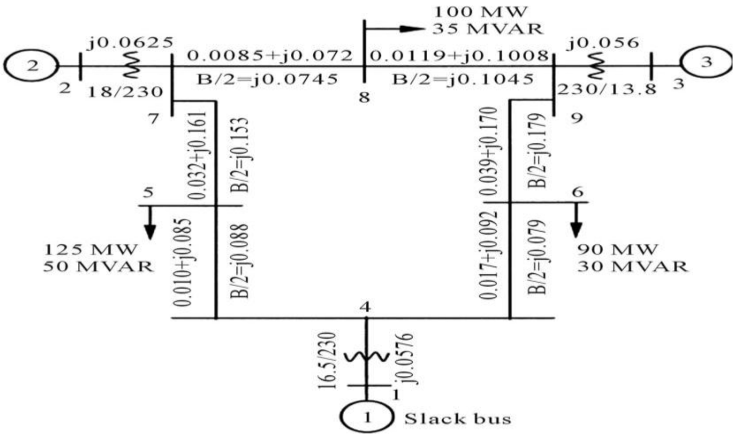

Figure 2: multimachine system

3.1 .CASE STUDY: A 9 bus & 3 generator are taken for analysis. There are 3 loads for the system and all the generators are steam driven. Transient fault is in between node 7 & 8.The analysis is done using MATLAB 6.5 package. System swing curve is tested for transient fault .Then the variation of swing curve with FACTS controller at node 2 is analysed. The variation is due to increased power transfer from generator to the load.the accelerated power pa for the system is given by,

$$P_a = P_m - P_g(\delta, U)$$

Pa = Input Power
Pg = Output power of the generator
δ= Rotor angle with respect to reference axis
U= UPFC Control variable

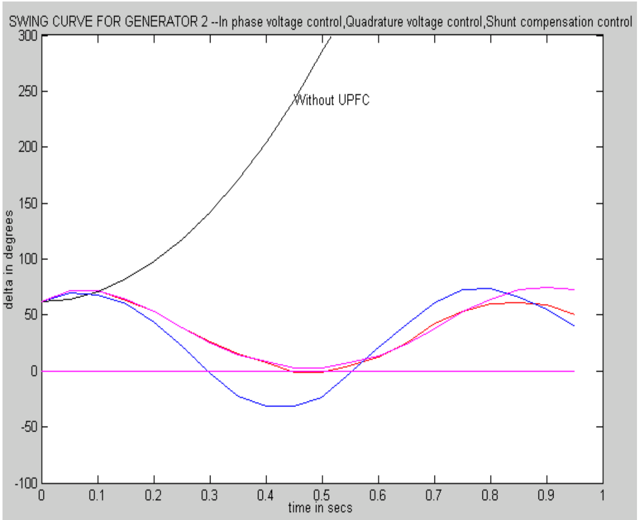

Figure 3: Swing curve for GR.2 with & without UPFC

From the results it is understood that by incorporating UPFC in multimachine system oscillations are effectively suppressed and the generators operating region will move from unstable state to stable state.

Dtrect Stabilityevaluation

For any two machine system transient energy can be related to equal area criterion. This is a fast method for stability evaluation, which doesn't require extensive solution of differential algebraic equations. For a two machine system it is a direct method which can determine stability based on the knowledge of the system state at the time of clearing. The transient stability margin is the difference between the critical energy and the transient energy acquired by the system during the acceleration period [8]. To improve the stability margin the controller must be capable of increasing the critical energy or reducing the acquired transient energy.[12,13]

The transient energy function is defined as

$$V(\delta,\omega) = \frac{1}{2}M(\omega - \omega_0\ )^2 - P_M(\delta - \delta_{sep}) + \int_{\delta_{sep}}^{\delta} P_g\left(\alpha, u(\alpha)\right)d\alpha$$

Where M= Inertia constant (MJ/MVA)

ω= angular velocity (rad/sec)

ω0= initial angular velocity (rad/sec)

δsep =rotor angle at the post fault stable equilibrium point.

The critical energy function is defined as

$$V_C = -P_m(\delta_{uep} - \delta_{sep}) + \int_{\delta_{sep}}^{\delta_{uep}} P_g\ \left(\delta, u(\delta)\right)d\delta$$

δuep =rotor angle at the unstable equilibrium point.

For a stable system Vc > V or Vc=V

Stability margin = critical energy – transient energy

Table 1: shows the stability margin of the 9 bus system with three control methods.

	Transient energy	Critical energy	Stability Margin	Stability nature
Uncontrolled	38.23	-51.76	-90.00	Unsatable
Voltage inphase	-44.29	18.38	62.66	Stable
Quadrature control	-38.94	9.24	48.18	Stable
Shunt compensation	-20.09	9.98	29.99	Stable

From the results it is observed that inphase voltage control reduces the first transient swing and increases the stability margin.

Fuzzy Logic Based Transientstability Analysis

Fuzzy logic is a convenient way to map input bspace to an output space. Fuzziness in general is simply one means of describing uncertainty. Such ideas are readily applicable to transient stability studies[14].

Fuzzy variables:

The fuzzy variables associated with the transient stability problem in the present formulation are

1. changes in delta
2. delta
3. margin of stability
4. upfc variable
5. stability nature

Change in delta , upfc variable,margin of stability and delta are the input fuzzy variable. stability nature is the output fuzzy variable.change in delta is considered as one of the fuzzy variables because its value changes based on the accelerating power of the machines.Finally margin of stability is treated as another fuzzy input variable since it predicts the degree up to which the machine is stable depending on the fault clearing time.If the stability nature value is 0 then the system is unstable, if the index value is 1 then the system is stable.

IF Then Rules:

Fuzzy rules are written to associate the fuzzy input variables to the fuzzy output variable.

Stability nature={if delta and change in delta and stability margin then stability nature}

Based upon this relationship maximum of 81 rules can be composed

Table 2: Fuzzy based uncontrolled system

Fuzzy inputs			Fuzzy output
Delta (rad)	Deldelta (rad)	Stability Margin	Stability nature
3.56	0.6581	-1.8890	0.0990 (unstable)
4.95	0.8130	-2.4639	0.0936 (unstable)
6.65	0.9679	-3.1668	0.0932 (unstable)
8.67	1.1227	-4.0188	0.0927 (unstable)

Table 3: Fuzzy inphase control

Fuzzy inputs				Fuzzy output
UPFC variable (Vpq)	Delta (rad)	Deldelta (rad)	Stability Margin	Stability nature
0.1	0.7696	0.27	0.8640	0.43 (stable)
0.2	-0.528	0.0765	3.3754	0.807 (more stable)

0.4	0.4673	0.2414	0.2484	0.284 (marginally stable)
0.7	-0.2885	-0.1275	2.7104	0.7657 (more stable)

Table 4: Fuzzy quadrature control

Fuzzy inputs				Fuzzy output
UPFC variable (ρ)	Delta (rad)	Deldelta (rad)	Stability Margin	Stability nature
134	1.3746	0.0754	-10.1467	0.0937 (un stable)
200	-1.3462	-.1974	2.9554	0.4342 (stable)
200	-0.6879	0.4938	0.4921	0.3229 (marginally stable)
230	-8.2539	-0.305	10.6808	0.7933 (more stable)

Table 5: Fuzzy shunt compensation control

Fuzzy inputs				Fuzzy output
UPFC variable (X)	Delta (rad)	Deldelta (rad)	Stability Margin	Stability nature
0.1	0.2854	0.6059	0.5737	0.3651 (Marginally stable)
-0.1	4.2449	-0.6014	-3.991	0.0966 (un stable)
0.1	0.1308	-0.3404	1.4839	0.4352 (stable)
-0.2	7.9819	1.1746	4.4805	0.7689 (more stable)

Table 6: Fuzzy combined control

Fuzzy inputs						Fuzzy output
Vpq	ρ	X	δ	Δδ	margin	Stability nature
0.4	350	-.1	7.94	1.11	8.11	0.7589 (more stable)
0.2	120	0.1	-.22	.35	2.53	0.43 (stable)
0.8	350	0.2	9.71	1,.25	1.34	0.28 (marginally stable)
1	350	0.2	2.41	0.80	-.56	0.09 (unstable)

From the results it was observed that the appropriate values for UPFC is selected to obtain high transient stability margin.

Conclusion

Transient stability study has been carried out for multimachine power system with & without UPFC. The effectiveness of three control aspects of UPFC has been done for a multimachine power system.the results of the above analysis will be useful in the coordination of UPFC controllers so that maximum effectiveness is achieved for transient swing reduction and improvement of stability margin.For the most complex situations fuzzy reasoning providews a way to understand system behavior by allowing us to interpolate apprtoximatly between observed input and output situations.

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