Inter-Area Oscillation Damping

1 Descriptions of Function

All prior work (intellectual property of the company or individual) or proprietary (non-publicly available) work should be so noted.

1.1 Function Name

Inter-Area Oscillation Damping

1.2 Function ID

T-4.18,T-6.10

"Automation system controls voltage, var and power flow based on algorithms, real-time data, and network-linked capacitive and reactive components."

1.3 Brief Description

Low frequency Inter-area oscillations are detrimental to the goals of maximum power transfer and optimal power flow. An available solution to this problem is the addition of power system stabilizers to the automatic voltage regulators on the generators. The damping provided by this technique provides a means to minimize the effects of the oscillations.

1.4 Narrative

Inter-Area oscillations result from system events coupled with a poorly damped electric power system. The oscillations are observed in the large system with groups of generators, or generating plants connected by relatively weak tie lines. The low frequency modes (0.1 to 0.8 Hz) are found to involve groups of generators, or generating plants, on one side of the tie oscillating against groups of generators on the other side of the tie. These oscillations are undesirable as they result in sub-optimal power flows and inefficient operation of the grid. The stability of these oscillations is of vital concern.

Although Power System Stabilizers exist on many generators, there effect is only on the local area and do not effectively damp out inter-area oscillations. It can be shown that the inter-area oscillations can be detected through the analysis of phasor measurement units (PhasorMeasurementUnit) located around the system. In a typical implementation, one or more of the generators in a system are selected as Remote Feedback Controllers (RFCController). The RFCController received synchronized phasor measurements from one or more remote phasor sources. The RFCController analysis the phase angles from the multiple sites and determines if an inter-area oscillation exists. If an oscillation exists, a control signal is sent to the generator's voltage regulator that effectively modulates the voltage and effectively damps out the oscillations.

To overcome the inter-area oscillation, new equipment such as Static Var Compensator (SVC) and various Flexible AC Transmission System (FACTSDevice) devices, are being increasingly used. These techniques have become possible due to the recent advancement in power electronic technology. The involvement of SVC and FACTSDevice in transmission network is through the so-called Variable Series Compensation (VSCController). Besides the FACTSDevice devices, the application of Super-Conducting Magnetic Storage (SMESDevice) to enhance the inter-area oscillation damping is also reported.

The key to coordinate RFCController, VSCController and various controllers is the using of PhasorMeasurementUnit synchronized with the Global Positioning Satellite (GPS).

The natural frequency and damping of the inter-area mode depends on the weakness of the tie and on the power transferred through the tie. The action of a dc link, parallel to the ac tie, is to strengthen the tie. Connection of two areas, through a dc link alone, does not introduce an inter-area mode owing to the asynchronous nature of a dc tie. Therefore, the inter-area instability is avoided. Indeed, that is one of the reasons for the growth of dc links.

1.5 Actor (Stakeholder) Roles

Describe all the people (their job), systems, databases, organizations, and devices involved in or affected by the Function (e.g. operators, system administrators, technicians, end users, service personnel, executives, SCADA system, real-time database, RTO, RTU, IED, power system). Typically, these actors are logically grouped by organization or functional boundaries or just for collaboration purpose of this use case. We need to identify these groupings and their relevant roles and understand the constituency. The same actor could play different roles in different Functions, but only one role in one Function. If the same actor (e.g. the same person) does play multiple roles in one Function, list these different actor-roles as separate rows.

Grouping (Community) '		***Group Description***
Inter-Area Oscillation Damping		
Actor Name	***Actor Type (person, device, system etc.)***	***Actor Description***
PhasorMeasurementUnit	Device	Phasor Measurement Unit (PhasorMeasurementUnit) - Calculate and transmit synchronized phasors at the required rate

Grouping (Community) '		*Group Description*
Inter-Area Oscillation Damping		
Actor Name	***Actor Type (person, device, system etc.)***	***Actor Description***
RFCController	Device	Remote Feedback Controller (RFCController) - Receive phasor measurement data from one or more Phasor Measurement Units; Detect inter-area oscillations; Issue local controls to the generator voltage regulator to damp out the inter-area oscillation
AVRController	Device	Automatic Voltage Regulator (AVRController) - Receives controls from the RFCController and adjusts the generator voltage based upon the received signal
VSCController	Device	Variable Serious Compensation (VSCController) - Receive phasor measurement data from PMUs located at both sides of the tie, adjust the variable series reactance by controlling the SVC and FACTSDevice devices.
SMESDevice	Device	Superconducting Magnetic Energy Storage (SMESDevice) - A energy storage device that stores energy in the magnetic field created by the flow of direct current in a coil of superconducting material that has been cryogenically cooled. It is designed to improve power quality, reliability and operational performance.
SMESDeviceSMESController	Device	Superconducting Magnetic Energy Storage system controller
FACTSDevice	Device	A power electronics based system and other static equipment that provide control one or more ac transmission system parameters to enhance controllability and increase power transfer capability,

Replicate this table for each logic group.

1.6 Information exchanged

Describe any information exchanged in this template.

Information Object Name	*Information Object Description*
Synchro Phasor	A phasor calculated from data samples using a standard time signal as the reference for the sampling process. In this case, the phasors from remote sites have a defined common phase relationship.
Controller Settings	Set points of the AVRController, FACTSDevice and SMESDevice systems.

1.7 Activities/Services

Describe or list the activities and services involved in this Function (in the context of this Function). An activity or service can be provided by a computer system, a set of applications, or manual procedures. These activities/services should be described at an appropriate level, with the understanding that sub-activities and services should be described if they are important for operational issues, automation needs, and implementation reasons. Other sub-activities/services could be left for later analysis.

Activity/Service Name	*Activities/Services Provided*
Send Phasor Measurement	Real-time transmission of Phasor Measurement data
Receive Phasor Data	Real time receipt of phasor Measurement data
Aggregate Synchronized Phasors	Upon receiving synchronized phasors from multiple sites, the received phasors are sorted by time tag and passed onto the analysis and feedback control algorithms
Coordinate Global Control	Based on the received phasor measurements and various control algorithms to coordinate the RFCController, VSCController and the SMESDevice controller.
Generator Voltage Control	A control signal (analog or digital) that is sent to the generator voltage regulator in order to modulate the generator voltage to minimize any inter-area oscillations
FACTSDevice Control	A control signal sent from VSCController to change the reactance of the FACTSDevice system

Activity/Service Name	*Activities/Services Provided*
SMESDevice Control	Control the charging and discharging of the SMESDevice system.

1.8 Contracts/Regulations

Identify any overall (human-initiated) contracts, regulations, policies, financial considerations, engineering constraints, pollution constraints, and other environmental quality issues that affect the design and requirements of the Function.

Contract/Regulation	*Impact of Contract/Regulation on Function*
PhasorMeasurementContract	

Policy	*From Actor*	*May*	*Shall Not*	*Shall*	*Description (verb)*	*To Actor*
PhasorMeasurementPolicy	PhasorMeasurementUnit			X	Comply with IEEE C37.118 standard	RFCController, VSCController

Constraint	*Type*	*Description*	*Applies to*

2 Step by Step Analysis of Function

Describe steps that implement the function. If there is more than one set of steps that are relevant, make a copy of the following section grouping (Preconditions and Assumptions, Steps normal sequence, and Steps alternate or exceptional sequence, Post conditions)

2.1 Steps to implement function

Name of this sequence.

2.1.1 Preconditions and Assumptions

Describe conditions that must exist prior to the initiation of the Function, such as prior state of the actors and activities

Identify any assumptions, such as what systems already exist, what contractual relations exist, and what configurations of systems are probably in place

Identify any initial states of information exchanged in the steps in the next section. For example, if a purchase order is exchanged in an activity, its precondition to the activity might be 'filled in but unapproved'.

Actor/System/Information/Contract	***Preconditions or Assumptions***
Phasor Measurement Unit	Must have voltage (3-phase) and time synchronization in order to compute phasors
Remote Function Controller	Must have valid communications from the remote sites; the controlled generator must be up and running

2.1.2 Steps – Normal Sequence

Describe the normal sequence of events, focusing on steps that identify new types of information or new information exchanges or new interface issues to address. Should the sequence require detailed steps that are also used by other functions, consider creating a new "sub" function, then referring to that "subroutine" in this function. Remember that the focus should be less on the algorithms of the applications and more on the interactions and information flows between "entities", e.g. people, systems, applications, data bases, etc. There should be a direct link between the narrative and these steps.

The numbering of the sequence steps conveys the order and concurrency and iteration of the steps occur. Using a Dewey Decimal scheme, each level of nested procedure call is separated by a dot '.'. Within a level, the sequence number comprises an optional letter and an integer number. The letter specifies a concurrent sequence within the next higher level; all letter sequences are concurrent with other letter sequences. The number specifies the sequencing of messages in a given letter sequence. The absence of a letter is treated as a default 'main sequence' in parallel with the lettered sequences.

Sequence 1:

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1.1 - Do step 1
1.2A.1 - In parallel to activity 2 B do step 1
1.2A.2 - In parallel to activity 2 B do step 2
1.2B.1 - In parallel to activity 2 A do step 1
1.2B.2 - In parallel to activity 2 A do step 2
1.3 - Do step 3
1.3.1 - nested step 3.1
1.3.2 - nested step 3.2
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Sequence 2:

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2.1 - Do step 1
2.2 – Do step 2
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#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
#	*Triggering event? Identify the name of the event.*[1]	*What other actors are primarily responsible for the Process/Activity? Actors are defined in section1.5.*	*Label that would appear in a process diagram. Use action verbs when naming activity.*	*Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step. "If …Then…Else" scenarios can be captured as multiple Actions or as separate steps.*	*What other actors are primarily responsible for Producing the information? Actors are defined in section1.5.*	*What other actors are primarily responsible for Receiving the information? Actors are defined in section1.5.* *(Note – May leave blank if same as Primary Actor)*	*Name of the information object. Information objects are defined in section 1.6*	*Elaborate architectural issues using attached spreadsheet. Use this column to elaborate details that aren't captured in the spreadsheet.*	*Reference the applicable IECSA Environment containing this data exchange. Only one environment per step.*
1.1	Any power system state	PhasorMeasurementUnit	Send Phasor Measurement	At all times, the PMUs in the field shall synchronously send phasors to the RFCController and VSCController.	PhasorMeasurementUnit	RFCController, VSCController	Synchro Phasor	Synchrophasors must be received at a rate of up to 60 phasors per second. Security is not crucial, however, data integrity is paramount, i.e., no faulty data shall be accepted.	Intra-Control Center

[1] Note – A triggering event is not necessary if the completion of the prior step – leads to the transition of the following step.

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
1.2	Power system disturbance (e.g. fault)	RFCController and VSCController	Coordinate Global Control	PMUs continue to send phasor data. Upon detection of df/dt > ε, trigger a storage local storage event; RFCs continue to synchronously receive phasor data and also detect the system event; The RFCController/VSCs, upon detection of the event, will trigger local data storage and coordinate the control action in order to conteract the detected inter-area oscillations.				The communication requirements differ from algorithm to algorithm. For the decentralized control, the system is decoupled with known system states.	NA
1.3 A	New control calculate	RFCController	Generator Voltage Control	The RFCController, having detected an inter-area oscillation and having computed an appropriate control action, sends the control information to the voltage regulator	RFCController	AVRController	Controller Settings	Voltage regulator control information shall be issued at the same rate as the synchro voltage receive rate	Intra-Control Center

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
1.3 B	New control calculate	VSCController	FACTSDevice Control	The VSCController, having detected an inter-area oscillation and having computed an appropriate control action, sends the control information to the FACTSDevice system	VSCController	FACTSDevice	Controller Settings		Deterministic Rapid Response Intra-Sub
1.3 C	New control calculate	SMESDevice SMESController	SMESDevice Control	The SMESDeviceSMESController, having detected an inter-area oscillation and having computed an appropriate control action, sends the control information to the FACTSDevice system	SMESDevice SMESController	SMESDevice	Controller Settings		Deterministic Rapid Response Intra-Sub

2.1.3 Steps – Alternative / Exception Sequences

Describe any alternative or exception sequences that may be required that deviate from the normal course of activities. Note instructions are found in previous table.

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments

2.1.4 Post-conditions and Significant Results

Describe conditions that must exist at the conclusion of the Function. Identify significant items similar to that in the preconditions section.

Describe any significant results from the Function

Actor/Activity	***Post-conditions Description and Results***

2.2 Architectural Issues in Interactions

Elaborate on all architectural issues in each of the steps outlined in each of the sequences above. Reference the Step by number.

Microsoft Excel
Worksheet

2.3 Diagram

For clarification, draw (by hand, by Power Point, by UML diagram) the interactions, identifying the Steps where possible.

3 Auxiliary Issues

3.1 References and contacts

Documents and individuals or organizations used as background to the function described; other functions referenced by this function, or acting as "sub" functions; or other documentation that clarifies the requirements or activities described. All prior work (intellectual property of the company or individual) or proprietary (non-publicly available) work must be so noted.

ID	Title or contact	Reference or contact information
[1]	Inter-area oscillation damping with power system stabilizers and synchronized phasor measurements	Snyder, A.F.; Hadjsaid, N.; Georges, D.; Mili, L.; Phadke, A.G; Faucon, O.; Vitet, S.; Power System Technology, 1998. Proceedings, POWERCON'98. 1998 International Conference on, Volume: 2, 18-21 Aug. 1998 Pages: 790 – 794 Vol.2
[2]	A fundamental study of inter-area oscillations in power systems	Klein, M.; Rogers G.J.; Kundur P.; Power Systems, IEEE Transactions on, Volume: 6, Issue: 3, Aug. 1991 Pages: 914 - 921
[3]	Coordinated Decentralized Optimal Control of Inter-Area Oscillations in Power Systems	Lie, T.T.; Li, G.J.; Shrestha, G.B.; Lo, K.L.; Energy Management and Power Delivery, 1998, Proceedings of

		EMPD'98, 1998 International
[4]	Using global control and SMESDevice to damp inter-area oscillations: an exploratory assessment	Heniche, A.; Kamwa, I.; Power Engineering Society Summer Meeting, 2000, IEEE, Volume: 3, 16-20 July 2000 Pages: 1872-1876 vol. 3
[5]	IEEE C37.118 Standard for Synchrophasors for Power Systems	Draft 3.20, Nov 9, 2003

3.2 Action Item List

As the function is developed, identify issues that still need clarification, resolution, or other notice taken of them. This can act as an Action Item list.

ID	Description	Status
[1]		
[2]		

3.3 Revision History

For reference and tracking purposes, indicate who worked on describing this function, and what aspect they undertook.

No	Date	Author	Description
0.	10/29/2003	Mark Adamiak	Complete the draft based on domain template version 1.21
1.	1/20/2004	Rui Zhou	Migrate the draft to domain template version 1.28