Adaptive Control and Power System Protection to Mitigate Wide-Area Blackouts

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Abstract - The main focus of this sstudy was to develop a wide-area based stability development control scheme for large interconnected power systems. A new method to identify coherent groups of synchronous generators involved in wide area system oscillations through WAMPAC system. As Synchronized Measurement Technology is an enabler and important element of WAMPAC and its applications. This study also reviews the state of the art of this WAMPAC systems architecture, communication's technologies and data management.

This application is developed to improve damping of power system oscillations in the future power system grid with the help of Wide Area Inter-Area Oscillation Control using excitation controller. In this way allowing enhanced dynamic performance under highly stress operation conditions. These enhanced system improved transfer capabilities and stability of the power system allowing the stability limit to be approached without threatening the system reliability and security.

Keywords: WAMPAC, PMU,PDC, Real Time Power system Simulation.

I. INTRODUCTION

Small disturbances or large disturbances like a high voltage transmission line fault or generator outage may consequence in un- damped power oscillations in a heavily loaded interconnected power system. If these un-damped oscillations are not adequately tackled, then the result in loss of synchronism of one or more group of machines and consequently cascading tripping from the rest of the power system leads to collapse the power network system. This is called rotor angle instability and is mostly dominated by low frequency inter-area oscillations [1]. To facilitate adequate damping to these inter-area oscillations, supplementary control of Flexible AC Transmission Systems (FACTS) devices and power system stabilizers (PSS) are used (referred as power oscillation dampers (POD). Over the years power system developer established synchrophasor technology through power system simulation studies and effectiveness of PMU-based wide-area measurements for power oscillation damping [2]. During these days, the research is focused on the robust design of the controller, communication latency compensation, resilience towards cyber suspicions and cyber-attacks, analysis with disparate PMUs, and controller design for hybrid AC/DC networks.

Wide area monitoring systems are used as additional controls for FACTS or HVDC systems to damp oscillations in grid. Although these deployments are important for oscillation damping, their comprehension requires either a new installation of FACTS / HVDC system or to amend the existing control loops in order to support both PMU-based signals and conventional signals. Note that the number of FACTS and HVDCs in today's power system is relatively small and installing such a system for the individual purpose of oscillation damping is not economical [3]. Additionally, utilizing wide-area measurement based control loops on HVDC/ FACTS systems together with the existing PSSs of a commercial AVR (Automatic Voltage regulator) for excitation may result in intervention between the controllers, which is not desirable [4].

In most of the cases AVR of large generators are equipped with built-in PSSs, it is attractive to explore the possibility of providing wide-area based external damping signals to these AVR, while minimizing changes to the existing AVR itself and their installations. At present available commercial AVR and power system operators cannot take advantage of wide-area measurements from PMUs as an input damping signal to generator AVRs because the AVR's are not yet capable to take advantage of synchrophasor technology. However, there is a possibility to disable the AVR's PSS function and take an advantage of PMU- based external damping signals, configured as an analog input to the AVR at the internal AVR's summing junction.

The effectiveness and utilization of supplying synchrophasor- based external damping signals to a commercial AVR for oscillation damping is demonstrated. The obtainable approach develops wide-area measurements from PMUs and further generates damping signals, which are fed to the AVR as an analog input. This approach utilizes the existing AVR installation without making any significant changes to it and/or its associated electrical installation. Additionally, the proposed method allows the user to select the input signals, utilized to generate the damping signal, and allows remote tuning of the controller parameters before supplying them to the AVR. Hence the proposed method can be used to generate damping signals adaptive to the changes in operating conditions or network topology, which can be configured remotely.

II. SYSTEM MODEL

Real time-Hardware in loop Experimental Setup

2-area 2-machine power system is modelled and configured for RT-HIL simulation as shown in Figure-1 in order to demonstrate the proposed wide area damping control and investigate the performance of the AVR, when provided with external damping signals. The system is stable under steady-state. Although, when a small perturbation in the form of a 5 % magnitude step at the voltage reference of the AVR of generator G2 is applied for 10 cycles, it results in an undamped inter- area mode of 0.91 Hz. The excitation control of generator G1 is supplied through the Unitrol 1020 AVR. Its internal PSS function disabled and configured to receive external damping signals through its analog inputs. The field voltage of G2 is supplied through an IEEE Type-1 DC1A exciter [5] without a stabilizing function (PSS disabled). Hence, the damping for inter-area oscillations is provided by Unitrol 1020 AVR at G1 using the external damping signals which are received through the Wide area damping control.

The workflow of the RT-HIL setup shown in Figure-1 is as follows.

1) The test system is executed in real-time using RTS.

2) Synchrophasor streams from both PMUs are concentrated through a PDC.

3) Three phase currents and voltages from Bus 1 and Bus 2 are fed to CTs and VTs of PMUs.

4) A protocol analysis M1 unpacks this PDC stream and provides raw numerical values of all the phasors available in the stream. Frequency and damping estimates of the modes are computed by the mode estimation module (Module- 2).

5) The raw synchrophasor measurements, frequency estimates of the modes and the signal latency information are accessed by the wide area damping controller.

6) The wide area damping controller performed the damping algorithm (M3) using the selected input synchrophasor measurement in real-time and produced a damping signal that is made available through one of the output channels of its output module.

7) This damping signal is fed to the Unitrol 1020 AVR as an analog input and is utilized internally in the AVR at the AVR's internal summing junction.

8) The excitation control signals from the AVR are fed to generator G1 executing in the RTS in real-time.

The AVR is interfaced with the wide area controller and real time simulator as shown in Figure-2. The real time simulator only offers currents and voltages within ±20 mA and ±10 V, respectively. The low-level signals of generator's G1 terminal voltage and stator current are boosted using linear amplifiers to 100 V and 1 A in order to make these signals compatible with the inputs of AVR. The field current measurement of G1 is supplied to the AVR using low-level outputs (±10 V) and one of the inputs of the AVR is configured for receiving these excitation current measurements.

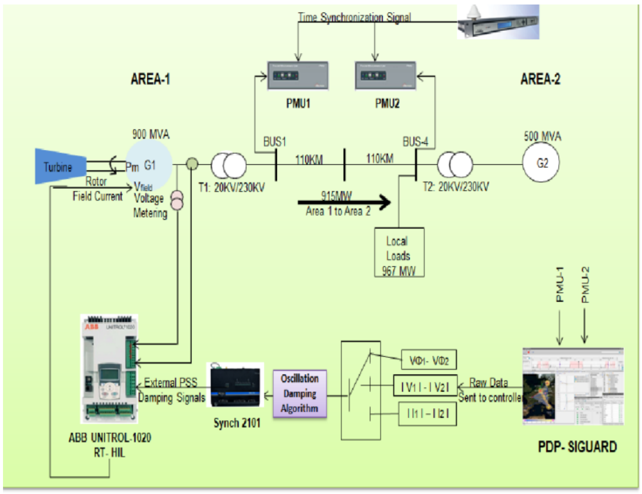

Figure-1: 2-area 2-machine model. G1 is equipped with Unitrol 1020 AVR .

Interfacing the AVR with the RTS and wide area damping controller

The damping signal generated from the wide area controller is accessed through its output module and is fed as an analog input to the AVR. This is achieved by configuring the corresponding analog input of the AVR to receive external signals. Through the AVR configuration software, the hardware was configured to receive the analog input from the external Moda signals and utilize them as primary stabilizing signal to the AVR. During the experimental tests, the primary stabilizing signal was toggled between the external damping signal from the WADC and its internal built-in PSS to perform comparative analysis [10].

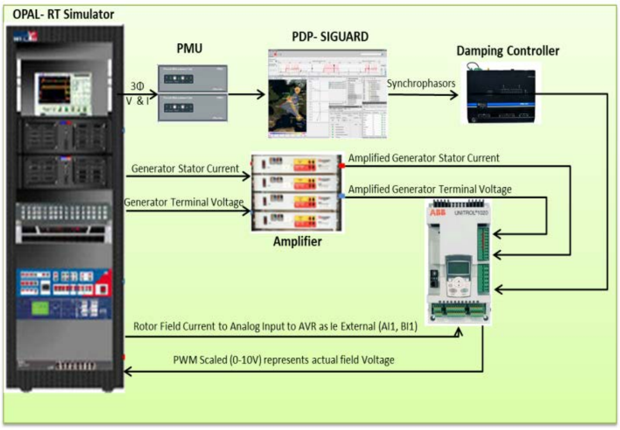

Figure-2: Interfacing Unitrol 1020 AVR with RTS and WADC.

III. PREVIOUS WORK

Excitation Control System (ECS) for synchronous generators is to enable power system stabilization by providing an additional input to the Automatic Voltage Regulator (AVR) for external stabilization signals. Feature by externally generating stabilization signals which are fed as an analog input to a commercial ECS. This allows bypassing the built-in PSS function in the ECS and gives more freedom to the end-user to utilize custom stabilizer models [7]. ABB's Unitrol 1020 Excitation Control System is coupled with Opal-RT's eMEGAsim Real-Time simulator to perform Hardware-in-the-Loop simulation of the ECS. The output of several stabilizer models is fed to the ABB's Unitrol 1020 ECS as external power system stabilization signals to analyze their performance for small signal stability enhancement [8].

IV. PROPOSED METHODOLOGY

A step-by-step approach is shown in Figure-3 to supply synchrophasor-based wide-area damping signals to an AVR. The summary is shown as below.

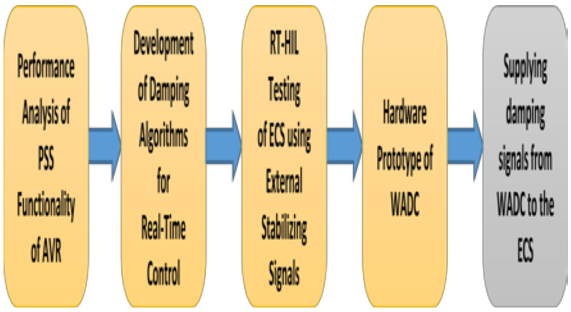

Figure-3: Steps involved in the development of Damping Controller based on wide area monitoring

The phasor-power oscillation damping method was deployed in an embedded controller16. This hardware prototype was tested in RT-HIL setup as shown in Figure-4 and was demonstrated to work satisfactorily to damp power oscillations.

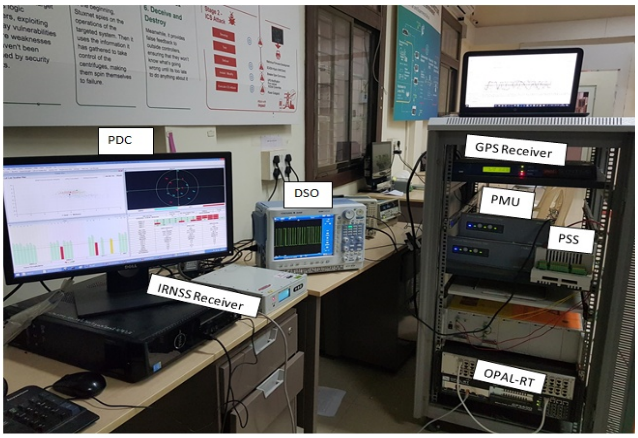

Figure-4: RT-HIL testing of hardware prototype of damping controller

V. SIMULATION/EXPERIMENTAL RESULTS

This section analyses the performance of the AVR for power system stabilization when provided with external damping signals from 3 different stabilizer models. A brief explanation of the different PSS models and their RT-HIL results are presented sequentially.

A. Multi-Band PSS

The IEEE type PSS4B PSS is described in the IEEE Standard 421.5. This block was implemented in the test case model and tuned to provide damping for the inter-area oscillation mode of 0.64 Hz. The model is shown in Figure-5 [6]. It consists of three bands namely low, intermediate and high band. The low band takes care of very slow oscillating phenomena (i.e. drift mode). The intermediate band is used for inter-area modes usually found in the range of 0.2 to 1.0 Hz. The high band deals with local modes with a typical frequency range of 0.8 to 4.0 Hz.

As shown in Figure-5, the input to the MB-PSS is the rotor speed deviation and output is a stabilizing signal which is provided as an external damping signal to the ABB's Unitrol 1020 AVR to provide adequate damping.

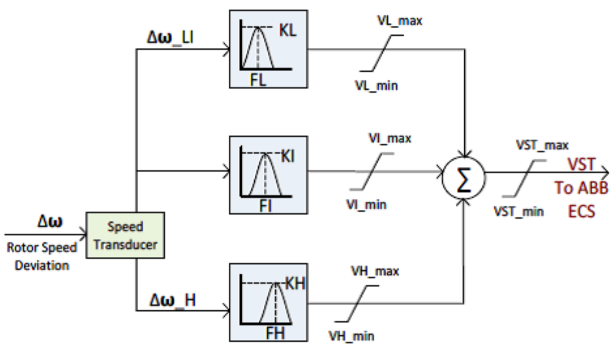

Figure-5: MB-PSS simplified model

KL = 30 ,FL= 0.05 Hz ; Ki = 40.0

FI = 0.80 Hz ; KH = 160.0 FH= 8.0 Hz

Result:

The response of all the above-mentioned methods of PSS is shown in Figure-6. With similar fault on the system the following voltage and current response have been recorded.

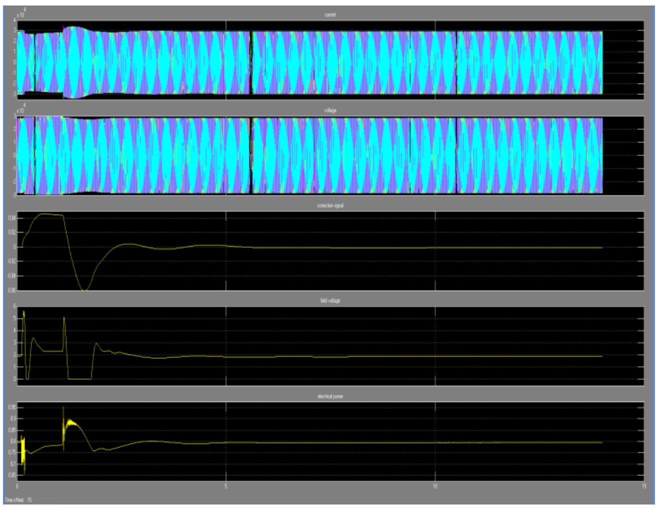

Figure-6: MB-PSS Results

B. Conventional Delta 'w' PSS

The simplest method to provide a damping torque in the synchronous machine is to measure the rotor speed and use it directly as an input signal in the stabilizer structure. This PSS is illustrated in Figure-7 and consists of a low-pass filter, a gain, a washout filter (which is effectively a high-pass filter), a phase compensation (lead-lag filter), and an output limiter. The general gain "K" determines the amount of damping produced by the stabilizer. The washout high-pass filter allows the PSS to respond only to transient variations in the speed input signal "dw".

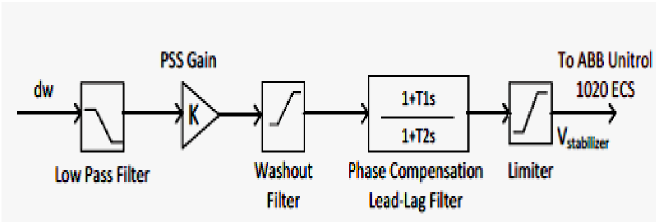

Figure-7: Model of conventional Δw PSS.

PSS Gain (K) is set to 20, T1 and T2 for phase compensation are set to 0.05 and 0.02 respectively.

Result:

The response of all the above-mentioned methods of PSS is shown in Figure-8. With similar fault on the system the following voltage and current response have been recorded.

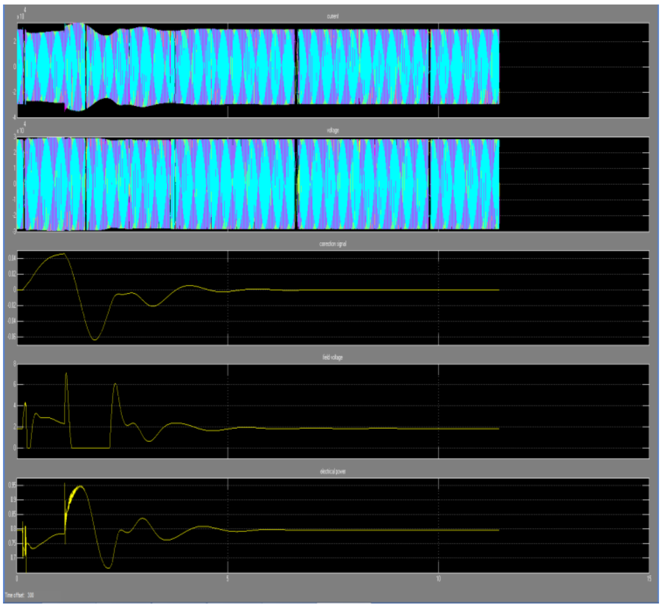

Figure-8: Δw PSS Results.

C. Conventional Acceleration Power (Delta Pa) PSS

The acceleration power of a generator is defined as the difference between its mechanical input power and electrical power output. This acceleration power is used as an input signal for the conventional PSS presented in Figure-9. The model of a Delta Pa PSS is shown in Figure-9.

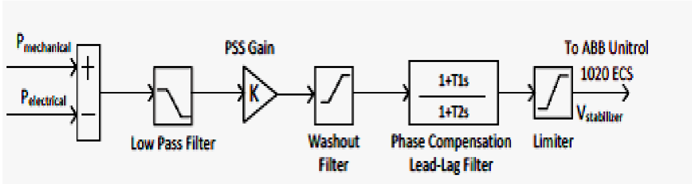

Figure-9: Model of conventional ΔPa PSS.

PSS Gain (K) is set to 3.5, T1 and T2 for phase compensation are set to 0.06 and 1 respectively.

Result:

The response of all the above-mentioned methods of PSS is shown in Figure-10. With similar fault on the system the following voltage and current response have been recorded.

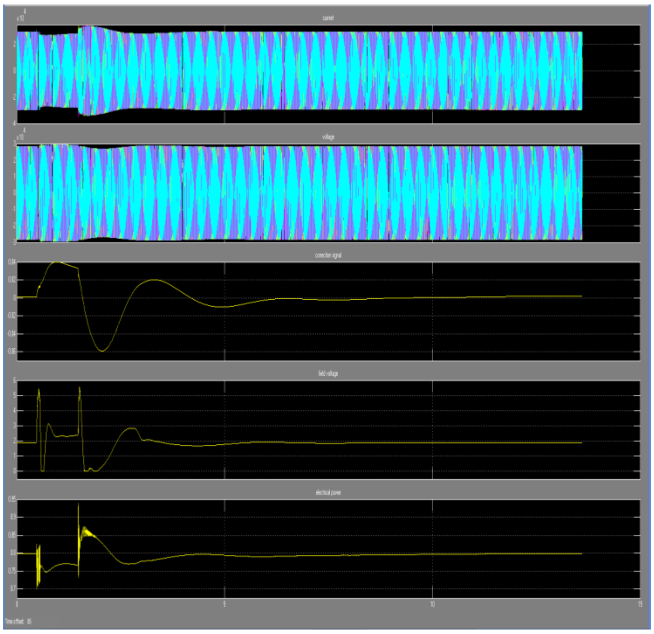

Figure-10: Conventional ΔPa PSS results.

VI. CONCLUSION

The stabilization capability of a commercial AVR is analyzed by providing it with external damping signals from different stabilizer models. RT-HIL simulation is performed for a 2-area 4-machine test system using Opal-RT real-time simulator and one of the generator in the test system is equipped with ABB's Unitrol 1020 ECS. The RT-HIL results have shown that the external damping signals from different stabilizer models can be fed to the commercial AVR to provide adequate damping to inter-area oscillations and thus liberating the users from the restriction of relying only on the built-in PSS implementation of the AVR.

This paper focused on the design, development and practical performance of synchrophasor-based WAMPAC application and provided thoroughly insight on the overall workflow from concept-to-deployment and end-to-end testing of WAMPAC applications. Within this framework, the thesis proposed WAMPAC applications that integrate existing infrastructures with synchrophasor technology to provide enhanced solutions for power system protection and control that can be immediately exploited and utilized by utilities. Further it has studied a Phasor based oscillation damper originally developed for SIMULINK. It has also successfully simulated the behaviour of the SIMULINK design using a hardware based (synch 2101) prototype which receives input data via synchrophasors. This hardware based prototype was also tested using a real-time simulator running an unstable two-area network and was accomplished of stabilising the power system. The prototype developed Wide Area Monitoring and Control System (WAMPAC), designed for enhancing the small signal stability of a future Jharkhand grid, has been presented.

FUTURE SCOPES

The flexibility that synchrophasor data brings to the power oscillation damping application opens wide scope for development of this design. The prototype demonstrated in this thesis approached on manual (operator) input to select an input signal. This process can be automated so as to choose a signal with the highest observability of a given oscillation mode. The required computations for this can be performed locally, on the micro-controller. Further automation is also required with the phase compensation section of the Phasor power oscillation damping algorithm. By using time stamped data at all states of the real-time data flow, the micro-controller can be used to monitor the signal propagation delay in real-time. Once this value of delay is identified, it can be used to compute the required phase compensation for a given input signal. This will also have the benefit of being able to switch to an alternate damping signal when the delay crosses unacceptable thresholds.

The most significant cost of the present design is the hardware and software platforms. This prototype has used software and hardware from different vendors. A cheaper and more standardized platform can be designed to support power oscillation damping controller code to an open hardware platform.

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