Review on Damping Wide-Area Oscillations with PMU in Power Systems

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Abstract – This paper presents an assessment on WAMPAC utility in transmission grid across global and its application. Additionally, 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

Electric grid is one of the most complex systems mankind ever built. It is considered to be the biggest engineering achievement of the 20th century and is serving relentlessly as the backbone of economy and critical infrastructure for any nation. Traditionally, it is divided into three verticals of generation, transmission and distribution sectors. Generation consists of large power plants (hydro, thermal, nuclear etc.) which generates electricity, which is then transported over high voltage transmission networks to long distances and distribute the electricity at low voltage to millions of customers and end-users. This scenario of power grid where energy and information flows only in one way from generation stations to consumers is changing with advent of smart grid technologies. Last decade or two has seen migration of traditional power grid towards embracing information and communication technologies (ICT) in digital transformation of power grid for monitoring and operation, penetration of more clean and renewable energy sources, more customer access-points and interaction. This has given way for many new technologies like wide area monitoring system (WAMS), geographical information system (GIS), asset performance monitoring (APM), microgrid and energy storage, digital grid and resilient grid to provide more reliable, efficient and economical grid operation. This has also opened-up new issues in the area of communication and cyber security. Visible and more prominent characteristics of smart grid are listed below:

- Increased observability and controllability of the power grid, including all its participating elements. This needs a higher level of syntactic and semantic interoperability of the various products, solutions and systems that build up a power system. Wide area measurement system (WAMS) deploying phasor measurement units (PMUs) is an attempt to acquire better insights of power grid for situational awareness to avoid blackouts and cascade failures in future along with System Integrity Protection Schemes.
- Smart grid is now being viewed as a cyber-physical-system (CPS) with traditional generation, transmission and distribution forming physical layer integrated with cyber layer of control, computing and communication.
- Consumer is more empowered with ability to push energy back in the grid as “Prosumer” allowing two-way energy and information flow.
- Increased penetration of clean and renewable energy sources (solar, wind) making traditional centralised grid to migrate to decentralised and distributed generation architecture. Energy storage is playing key-role in grid stability due to intermittency of renewable energy sources.
- Smart metering could significantly improve knowledge of what is happening in the distribution grid, which nowadays is operated rather blindly.
- HVDC and FACTS improve the controllability of the transmission grid. Both are actuators, e.g. to control the power flow. The controllability of the distribution grid is improved by load control and automated distribution switches.
- At the heart of smart grid vision is increased use of communication and IT technologies, including an increased interaction and integration of formerly separated systems. Recent trend is towards leveraging big data analytics, internet of things (IoT) technologies, Blockchain and artificial intelligence (AI) for condition monitoring system, power quality monitoring, meter data analytics, energy trading, transaction settlement and enterprise business intelligence.
- Increased attention towards cyber security of critical information infrastructure and physical assets. All above attributes are adding more hackable entry-points in otherwise air-gapped power grid making it more vulnerable to cyber-attacks.

One of the growing apprehensions, supposed to cause limitation in the amount of power transfer across transmission networks, is power system oscillations and their impact on the stable operation of power systems. Power system oscillations are related to the small signal stability of power systems and are unfavourable to the goal of maximum power transfer and power system security [1]. Early efforts to control these oscillations include using damper windings on the generator rotors and turbines, which establish to be acceptable at the time. However, as power systems began to manage closer to their stability limits, the weakness of a synchronising torque among the generators was recognised as a major cause of system instability to which the introduction of Automatic Voltage Regulators (AVRs). It helped to attempt the issue and improve the steady state stability of the power system. The issue of transferring large amounts of power across long transmission lines are begin with the creation of large interconnected power systems. Additionally, supplementary controllers into the control loop, such as the introduction of traditional Power System Stabilisers (PSSs) to the AVRs control loop on the generators, provide the means to reduce the inhibiting effects of low frequency oscillations which limit the amount of power transfer. The traditional PSS work well at the particular network configuration and steady state conditions for which they were designed. Their performance will deteriorate on the conditions change.

As power systems are becoming more complex, the need for maximum utilisation is becoming a necessity. Therefore, the requirement for new control schemes to improve system stability and allow for such maximum utilisation to be evident without negotiation of system security and reliability is appropriate the focus of system operators and research development. These developments of such schemes needs essential and necessary further development of tools to operate and control these systems in a reliable manner by making use of recent developed technologies in many other fields of engineering, such as communication technology and IT development.

II. KEY CHALLENGES IN POWER SYSTEM CONTROLS AND OPERATION

The complexity of controlling and operating bulky interconnected power systems is growing as power systems expand in size and familiarity significant changes in their operational criteria. Moreover, the increase in size, these changes are also due to the introduction of new generation technologies in the form of renewable energy resources and distributed generators. Transmission networks in India are squeezed between two conflicts. One side, the continuous increase on the demand for electricity, deregulation of the electricity markets, privatization and the economic pressures are approaching to transmission and grid operators to maximize the use of transmission assets. Other side, increasing concerns about the reliability of supply, especially following the 2012 major grid blackouts in North India, are forcing the same players to be more careful about how far they can drive the grids' infrastructure on no risk with the systems' security. Obviously, the abovementioned conflicts can be faced. Below mention some other keys challenges of power system operation and control are following.

- Maximizing the use of the existing networks by improving the level of controllability over these networks and making certain that they are operated in an efficient way; hence improved utilisation of these assets.
- Strengthening the networks by expansion of the infrastructure and building more transmission lines.
- Planning and construction of strong ultra high voltage (UHV) power grid.
- Large-scale thermal power, hydropower and nuclear power bases integration of power grid.
- Large-scale renewable energy sources integration of power grid.
- Distributed generation and coordinated development of the grids of various voltage ratings.
- Study on smart grid planning and developing strategy.
- Improve the controllability of the power grid based on power electronics technology.
- Superconductivity, energy storage and other new technologies widely used in power system.
- The application of emergency and restoration control technology in power system.

III. APPROACH TO RESOLVE KEY CHALLENGES

As mentioned above, modern power systems in India are experiencing significant changes in their operational criteria and are consequently, facing a number of challenges. The conclusion of most of these challenges is that pressure has been put on these systems and on grid operators to maximize the utilization of high voltage equipment which tends to the operation of this equipment closer than ever to its stability limit. The approach of maximum utilizations of existing assets is achievable, providing that these systems are equipped with well-designed and well-coordinated protection and control schemes that make sure safe and stable operation of these systems.

In particular, the developing technology of Wide-Area Measurement Systems (WAMS) and the use of Phasor Measurement Units (PMUs) have made the monitoring of the dynamics of power systems in real-time, shows potential aspect to improve and maintain systems stability under stressed operation conditions. The development of the synchronised Phasor Measurement Units (PMUs), which comprises advance in communications, computation capabilities and Global Positioning System (GPS) technologies.

WAMS are needed for monitoring and managing stressed power systems [2]. The interest in phasor measurement technology has received a great deal of awareness in recent years. This requirement for the best estimate of the power system's state is acknowledged to be crucial element in enhancing its performance and its resilience to catastrophic failures. The information captured by these types of measurement systems not only allows for superior monitoring of the power system, but also offered the require tools to design proper control and protection schemes based on wide-area dynamic systems. Such schemes will facilitate to enhancement of power systems performance [3]. It will help to ensure that the challenges are met effectively. Wide-Area Measurement Systems (WAMS) open a new way to power system stability analysis and control. These systems are capable of providing dynamic snapshot of the systems states in real-time and update it every 20 ms [4]. Such a accurate understanding of the operation conditions contributes appreciably to achieving much enhanced performance levels of power systems. The effectiveness of the design of control schemes based on wide-area information can also contribute to better systems utilization. The enhancement of the system performance based on WAMS technologies includes [5]:

- Increasing power transmission capability with no reduction of system security.
- Improving exploitation of existing assets.
- Avoiding large area disturbances.
- Assuring power system integrity.
- Better access to low-cost generation.
- Better visualization and assistance tools for operators to manage the system.

Installing the phasor measurement units (PMUs) and obtaining the important information about the PMU/WAMS system through continuous observations of system events. Most installations are focusing for a wide-area measurement systems (WAMS) in which measurements acquiring from various locations on the grid and can be collected at central locations. Those central locations of wide range monitoring, protection and control applications can be deployed.

IV. WAMS APPLICATION

Wide Area Measurement, Protection and Control (WAMPAC) heavily relies on Synchronized Measurement Technology (SMT). Most of the applications of grid monitoring and control of WAMPAC are developed based on SMT. A few such applications of SMT are presented in this chapter. It also provides an overview of the state of the art and global experience of these applications.

Mainly, SMT applications are divided into off-line applications and on-line applications of power grid [6]. On-line applications of SMT are used to help grid operators in real time, by offering on-line monitoring, protection and control. Whereas. off line applications are mainly used for post-mortem analysis for forensic purposes, to develop and validate the system models, to make system planning and off-line stability studies more reliable. Such type of analysis gives a comprehensive understanding of dynamic behavior exhibited by the grid. However, SMT is still evolving technology which lacks maturity and validation of a few applications [7].

Offline Applications

- Broad application for post event (forensic) investigation. It helped in finding the type of fault (phases involved), Identification of the phase in which fault has occurred, Fault clearing time Protection misoperation detection
- Detection of several modes in low frequency oscillation using techniques like Fast Fourier Transform, Modal and Prony Analysis etc.
- Detection of inter area/local mode oscillations
- Power system dynamics Visualization with the assistance of State measurements.
- Visualization of phasors, angular separation, sequence components, inter area oscillations, df/dt, voltage dip during fault, voltage recovery after clearance of fault, synchrocheck etc.
- Validation of operation of under frequency and df/dt relays due to convenience of high resolution frequency data at the control center.
- Validation of Transfer Capability for evacuation of generation; Oscillations were visible when the actual power flow crossed the prescribed limits
- Validation of operation time of SPS used for inter tripping generating units after tripping of evacuation lines
- Validation of Steady state network model in SCADA/EMS
- Used in computation of Frequency Response Characteristic
- Identification of coherent group of generators during grid event
- Observing SVC response during grid events

- Validation of fault level as reported by Disturbance Recorder and as computed from offline studies

Online Applications

- Situational awareness through real time monitoring of voltage, frequency, df/dt and angular separation.
- Event of transmission line tripping/ restoration within a flowrate by observing Step change in voltage magnitude, angular separation, and Step change in line current (MW & MVAR).
- Event of generator tripping by observing Frequency decline, increase in df/dt, change in angular separation and decrease in voltage magnitude
- In case of autoreclosure by change in df/dt.
- In case of load throw off by observing sustained High frequency, sustained abnormal phase angle separation and sustained high voltage.
- Help in subsystem synchronization during restoration by using standing phase angle separation and phase sequence.

V. LITREATURE REVIEW

Synchronous generator's terminal voltage regulation, a commercial Automatic Voltage regulator (AVR) [8] may also provide Power System Stabilizer (PSS) functions to damp power system oscillations [9]. Small disturbances may result in un-damped oscillations in a heavily loaded interconnected power system [10]. Un-damped oscillations, if not mitigated, result in loss of synchronism of one or a group of machines from the rest of the power system and may lead to a system collapse [11].

Different vendors have deployed diverse PSS types in their AVR units, which can be configured to provide damping for power system oscillations. These built-in PSSs utilize single or multiple local input measurements (e.g. rotor speed, rotor angle deviation and generator's accelerating power) to damp oscillations. These input measurements are pre-configured and cannot be modified by the user. The user must tune the available pre-defined parameters to provide oscillation damping. These configurations have to be deployed locally at the power plant and cannot be modified remotely by the system operators.

With the deployment of Phasor Measurement Units (PMUs) in the power grid, there is a possibility of utilizing wide-area measurements for enhancing real-time detection and control of small-signal instability [12, 13].

The significance of PMU-based wide-area measurements for power oscillation damping (POD), power system simulation studies have demonstrated by Power system researchers over the many years [13-18]. Local signals utilized by conventional damping controllers might not be better than wide-area measurements for inter-area modes observability.

Despite the fact that the possibilities of wide-area damping control application implementation are very encouraging, to the information of the authors, there are moderately not many of such deployment in the field. One pilot test was completed in the Norwegian power system using voltage phase angle measurement from PMUs as detailed in [19].

This WADC gives damping signals to the voltage controller of a Static Var Compensator (SVC). Despite the fact that the field preliminaries were effective, they were inadequate to summarized whether the WADC performs more acceptable than the local estimation based damping controller. The project of a WADC in China Southern Power Grid (CSG) is accounted for in [20]. This wide area damping control employs PMU measurement contribution and control two HVDC system for power system damping. Despite the fact of close-loop field testing of CSG's WADC was successful, it remains in open-loop trial operation mode to further study its impact on system's dynamics. A WADC equipment model controller is currently experiencing open-loop testing at the Bonneville Power Administration (BPA) synchrophasor research center as revealed in [21]. This WADC uses PMU estimations to ascertain frequency distinction between two regions, which is calculate to register a directional power command used to modulate the controllers for oscillation damping.

The previously mentioned WADC frameworks have been executed as supplementary controls for Flexible AC Transmission Systems (FACTS) or HVDC frameworks to damp oscillations. Though these arrangements are valuable improvements for oscillation damping, their apprehension involves either a new installation of FACTS / HVDC system or to modify the existing control loops in order to support both local (conventional) signals and PMU-based signals. Note that the quantity of FACTS and HVDCs in the present power system is moderately small and introducing such a framework for the sole reason for oscillation damping is not economically sound [22]. Besides, using wide-area measurement based control loops on FACTS/HVDC system together with the current PSSs of a commercial AVR may result in interfering between the controllers, which isn't appropriate [23, 24].

As many of the AVRs of large generators are equipped with built-in PSSs, it is appropriate to explore the possibility of providing wide-area based external damping signals to these AVR's while minimizing changes to the existing installations and the AVR itself.

The stabilization capability of a commercial ECS 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 ECS 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 ECS [25].

VI. PROPOSED WORK

A step-by-step approach is shown in Fig. 1 to supply synchrophasor-based wide-area damping signals to an AVR. The summary is shown as below.

2-area 4-machine power system is modelled and configured for RT-HIL (Opal-RT) simulation as shown in Fig. 6.12 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 un-damped 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 [26] 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 (OPAL-RT) setup shown in Fig. 1 is as follows.

- ➢ The test system is executed in real-time using RTS.
- ➢ Synchrophasor streams from both PMUs are concentrated through a PDC.
- ➢ Three phase currents and voltages from Bus 1 and Bus 2 are fed to CTs and VTs of PMUs.
- ➢ 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).
- ➢ The raw synchrophasor measurements, frequency estimates of the modes and the signal latency information are accessed by the wide area damping controller.
- ➢ 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.
- ➢ 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.
- ➢ The excitation control signals from the AVR are fed to generator G1 executing in the RTS in real-time.

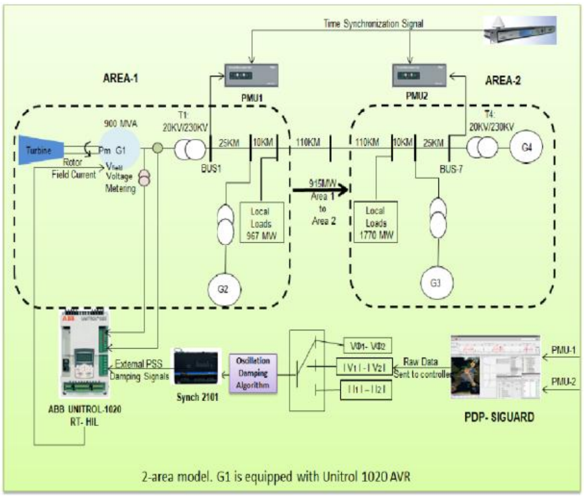

Figure -1 Interfacing Unitrol 1020 AVR with RTS and WADC.

VII. CONCLUSION

This paper mentioned the modern status of the research and trends inside the field of WAMS in transmission networks for enhancement of strength grid monitoring, stability and utilization of sycnchrophasor enabled protection relays to act as PMUs. Additionally, this paper affords the studies articles to be had for the integration FACTS, PMU & PDC surroundings and its implications. Authors will use this literature survey for the proposed assignment of WAMPAC application as external PSS.

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