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A Novel Technology to Improve Grid Frequency Response on Electrical Power System with High Level of Renewable Generation Penetration

VINAY KUMAR, SUNIL BHATT
Department of Electrical & Electronics Engineering, Dr. A. P. J. Abdul Kalam University, Indore
Corresponding Author Email: kumarvinay874@gmail.com

***Abstract*— As variable renewable generation, such as wind and solar, is increasing worldwide and synchronous generation is displaced, the facility system frequency response and reliability are strongly challenged because these resources do not inherently contribute to the inertial response of the facility system. This paper demonstrates that both dynamic and continuous load control is in a position to supply a big portion of the anticipated need for inertia and fast frequency response required to integrate high level of renewable resources and to take care of power grid reliability.**

***Index Terms*—Inertia, Demand response, frequency control, quasi-inertial response.**

I. INTRODUCTION

Water The instantaneous balance of power supply and demand is that the fundamental reliability criterion of electrical power systems. When an imbalance occurs, the system frequency deviates from its par value. Therefore, frequency control (the action of maintaining system frequency within a given tight range) is prime so as to supply a reliable and secure power system. Traditionally, one among the most principles that supports the steadiness and reliability of the electrical grid is to believe large synchronous rotating mass in bulk generating plants to supply the inertia and governor response required for the electrical grid to manage most loading and transient events and to stop adverse impact for the users. The increasing penetration of renewable energy production like wind generation and solar photovoltaic, distributed generation and other electronically coupled resources combined with the decommissioning of huge coal and atomic power plants introduces new challenges in electric power system particularly thanks to their well-known inherent intermittency.

Power system inertia is significant because it determines the sensitivity of the system frequency towards supply demand imbalances. for instance, with less power grid inertia, the frequency is more sensitive to temporary imbalances. Inertia is that the instantaneous response that's automatically self-deployed from synchronous machines following disturbances and consequently become a key determinant of the strength and stability of the facility system.

The aforementioned non synchronous generation growth in power systems reduces their inertia making them more vulnerable. It also enhances the challenge of frequency control to a critical level.

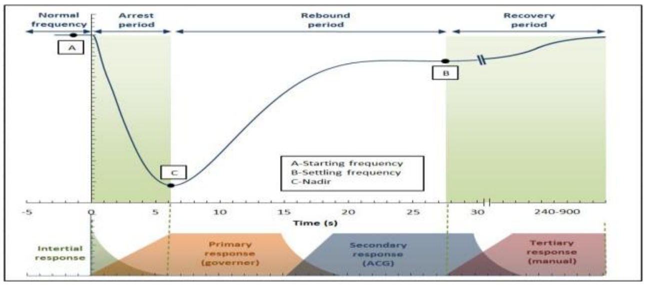
In today's power systems, inertia and frequency response became a serious concern and a crucial design constraint mainly because there's little or no thanks to change or control the initial rate of change of frequency (RoCoF) and therefore the frequency nadir. there's therefore a growing got to assure the supply of a sufficient amount of inertia and lots of power systems (ex: Ireland [1], Texas [2], Hydro-Québec [3], New Zealand [11]) are reviewing their grid code to make sure that their inertial response is adequate. Load is technically capable to help within the balancing of the facility grid and its frequency control. By modulating the load, it's possible to supply reliability services like inertia and first response that are the foremost technically challenging services to be supported.

Altogether, the aim of this study is for instance, using time domain simulations, the power of Dynamic and Continuous Load Controller (DCLC) to mitigate excessive high Rate of Change of Frequency (RoCoF) and excessively low frequency nadir caused by reduced power grid inertia in power systems with significant penetration of renewable resources. Section 2 gives a summary of Frequency response and mechanism involved in its control.

II. FREQUENCY RESPONSE OVERVIEW AND NEW THREAT TO POWER SYSTEM RELIABILITY

Frequency control (i.e. maintaining system frequency within a decent range) is prime to maintaining a reliable and secure electrical power system. Frequency control occurs over multiple time frames, requires supply and demand forecasting, and involves coordination among many various systems. the best threat to frequency stability and power grid reliability results from the sudden loss of an outsized generation resource. Synchronous generators and motors inertia, governors' actions and their settings, central automatic generation control (AGC), Secondary and Tertiary system, provision for spinning and non-spinning reserve are all working together, in their respective time-frame, to reestablish frequency at its par value after an occasion involving a generation-load imbalance.

Figure 1 below shows a classical frequency excursion response after a generation loss. Immediately following the event, the inertia of synchronous rotating machines will supply the energy difference. the dimensions of the resource loss and therefore the inertia of the system determine the slope of the frequency decline (RoCoF). Following this first response, generator governors sense the frequency change and start to regulate their input to extend the energy needed. Governor response speed depends on the sort of turbine; the shortest response being provide by turbine, followed by turbine. The longest time delays are usually related to high head hydro turbine that need long times until the supplementary mass flow throughout the turbine. the mixture of synchronous inertial, turbine governors and cargo response (mostly induction motors) arrest the decline at the frequency nadir (Point C in fig 1) when their energy contributions equals the generation lost. After it's been arrested, frequency rebounds to the settling frequency (Point B in fig. 1) because the turbine governor deploy spinning reserve. The system frequency then stabilizes at an off-nominal frequency during which the system remains vulnerable.



The second phase which has begun with the AGC automatic deployment is followed by secondary response (manually deployment of reserve) to return the frequency back to its nominal level. Finally, the slower Tertiary response, which are mostly off-line generation recalled in commission, replace the first and Secondary resources and reestablish the facility system ability to counter another contingency.

III. CONCERNS WITH FREQUENCY RESPONSE IN POWER SYSTEM WITH HIGH LEVEL OF RENEWABLE ENERGY SOURCES PENETRATION

Most renewable resources, as well as battery storage, do not contribute to system inertia and frequency response because they are electrically connected to the power system through an electronic inverter. Modern wind turbines are equipped with back-to-back converters (doubly fed induction or direct drive synchronous generators) while solar panels and battery storage have no rotating part and are thus inertia less.

There is a growing concern in the power system planners and operator's community regarding the increased penetration of renewable resources in light of its impact on power frequency response and stability.

This concern is more accurate on power systems facing high level (> 40 %) of Instantaneous Non-Synchronous Resources Penetration (INSP).

IV. NEED FOR NEW FASTER FREQUENCY SERVICE; THE QUASI-INERTIAL RESPONSE

With less synchronous generation online, there is a clear need for new fast-acting response systems that change frequency. Fast meaning here that the full response should be delivered in 0,5 - 3 seconds range after a generation loss. Aim for this quasi-inertial response is clearly to supplement the inertial response from synchronous machines before actions from governor take place thus helping with the symptoms of low system inertia or too slow governor's response in power systems facing high INSP. The inertial response that a synchronous machine can provide is independent of the machine's power output. Similarly, the entire system response to an initiating event is decided by the summation of the contributions from each of the web synchronous machines. It is important to note that inertial response reliability value decreases as the time delay associated with the delivery of primary frequency response (essentially turbine governors) decreases. If all time delays associated with the governor's action could be eliminated, then inertial response would have little value.

In contrast, quasi-inertial response that can be supplied immediately (without significant time delay) has a higher reliability value than governor response because it requires less inertial response to achieve smaller arrested frequency deviations. Quasi-inertial response is not strictly equivalent to synchronous machine inertia, which is an autonomous and instantaneous response of synchronous machines because it is done through a controlled action in response to falling system frequency. However, the law of energy conservation and the strong coupling between the rotor speed of synchronous machines and the frequency also implies that inertia will instantaneously release only the exact amount of energy related to the power generation imbalance, no more, no less.

V. LOAD AS A QUASI-INERTIAL RESPONSE PROVIDER

Demand response (DR) is defined by the FERC [7] as "Changes in electric usage by end-use customers from their normal consumption patterns in response to changes within the worth of electricity over time, or to incentive payments designed to induce lower electricity use sometimes of high wholesale market prices or when system reliability is jeopardized".

It has been often highlighted [8] that demand response is the largest underutilized reliability resource in the world. Historic demand response programs have focused on reducing overall electricity consumption and shaving peaks but haven't typically been used for reliability response.

VI. SYSTEM UNDER STUDY AND SIMULATIONS

One of the aim of this study is to illustrate, using time domain simulations, the ability of Dynamic and Continuous Load Controller (DCLC) to mitigate excessive high Rate of Change of Frequency (RoCoF) and excessively low frequency nadir caused by reduced power system inertia in power systems with significant penetration of renewable resources. The power system under study is a large 60 Hz isolated power system of about 30 GW with mainly hydroelectric resources. Siemens Power System Simulation for Engineers (PSSe) version 33 with only standard IEEE models (GENSAL, EXST1, IEEEST, HYGOV, CSVGN5, LDFRAR) is used for all time-domain simulations.

As a reference, this base case has been used by Systemex Energies in its studies associated with proof of concept to demonstrate the feasibility, the capability and the robustness of its technologies in controlling and improving frequency response following the tripping of a large generator for a large public power system. Subsequent detailed analyses done by the planning team of this utility corroborate results presented here.

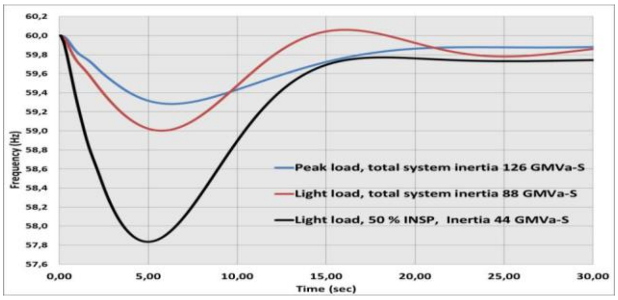
System frequency response

In this section, we will compare the frequency response of the system under study in the following conditions:

Case 1: effect of a reduction of power system inertia on frequency response for the sudden loss of 1000 MW of generation.

Case 2: impact of DCLC controller on frequency response with two different control strategies; a RoCoF target of -0,50 Hz/sec and a RoCoF target of -0,30 Hz/sec.

As it can be seen, for 1000 MW generation loss, it is possible to maintain the system frequency above the frequency target in cases without wind turbine generation but not in?? case with 50% of INSP. RoCoF changes from -0,15 Hz/sec in the peak load condition to -0,30 Hz/sec in the light load conditions to -0,70 Hz/sec in the light load conditions with 50% INSP. This is a good example of the impact on frequency response that the displacement of traditional resources by electronically coupled resources during light load periods can .We also observe that nadir is lower and happens faster when inertia is reduced. Table 2 resumes the main results.

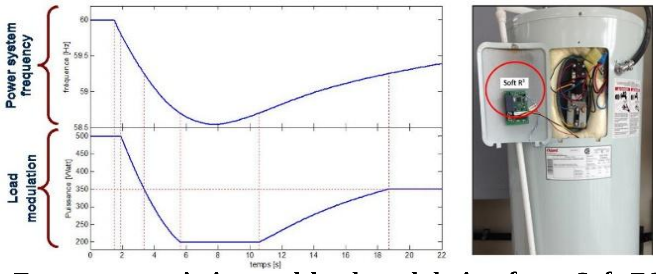


Effect of DCLC controller on RoCoF and nadir

Figure compares power system frequency response for the tripping of 1 000 MW generator in light load case with 50 % of INSP (the black curve of fig. 2) with the same event but with DCLC added to improve power system frequency response. The green curve illustrates frequency response when DCLC control strategy is adjusted to meet a RoCoF target of -0,50 Hz/sec and the brown curve when a RoCoF target -0,30 Hz/sec is used. In the cases studied here, a maximum of 450 MW of load is modulated to reach the -0,50 Hz/s target and 600 MW for the -0,30 Hz/s target.

VII. RESULT AND CONCLUSION

Regulation as well as solutions for grid with intermittent power generation or high ramp up problem. The company has entered into a co-development phase in order to demonstrate the technical and commercial feasibility of Soft-R3Tm. This major project has confirmed the ability of the Soft-R3TM solutions to provide operating reserves and frequency regulation, to improve the reliability of the grid and the frequency behaviour, to accurately measure grid frequency using robust filtering algorithms and to meet the high standards of public utilities requirements. The prototypes installed in real conditions on domestic water heater are totalizing more than 20,000 hours of operation so far. The next step is to plan a larger demonstration phase by year-end 2015. Figure 4 shows load modulation when Soft-R3TM control strategy is adjusted to supply spinning reserve once the device is installed on an electrical hot-water heater.



Frequency variation and load modulation for a Soft-R3 installed on a domestic water heater

Traditionally, one of the main principles that supports the stability and reliability of the electric power systems has been to rely on large synchronous rotating mass to provide the inertia and governor response required to assure frequency response. However there is a growing concern in the industry with the penetration of non-synchronous renewable resources which do not contribute to power system inertia making the power system more vulnerable and enhancing the challenge of frequency control to a critical level. One of the main reliability threats of reduced power system inertia is the augmented steepness of the RoCoF that could cause equipment tripping and leave insufficient time for governors to deploy and arrest system frequency decline before UFLS is initiated. The primary objective of this paper was to demonstrate the possibility to modify the rate of change of the frequency during a loss of generation and to remove uncertainty associated with variation in system inertia. Although each grid has its own characteristics, DCLC has enough flexibility in its control strategies and robustness in its mode of action to be effective in all kinds of situations. DCLC is continuous, autonomous, without telemetry requirement, fully customizable load controller and may be seen as an ideal and evolved turbine governor. Unlike wind synthetic inertia system and other on-off demand response controller, its effects on frequency response is simple, adjustable, robust, predictable and does not rely on external conditions (like wind).

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