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

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Abstract

As variable renewable generation, such as wind and solar, is increasing worldwide and synchronous generation is displaced, the power system frequency response and reliability are strongly challenged because these resources do not inherently contribute to the inertial response of the power system. This paper demonstrates that both dynamic and continuous load control is able to provide a significant portion of the anticipated need for inertia and fast frequency response required to integrate high level of renewable resources and to maintain power system reliability.
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Keywords: — Inertia, Demand response, frequency control, quasi-inertial response

Résumé

L’augmentation croissante de la production renouvelable dans le portefeuille des ressources vient menacer la réponse en fréquence et la fiabilité des réseaux; ces nouvelles ressources ne contribuant pas de manière naturelle à l’inertie. Cette publication démontre que le contrôle dynamique et continu de la charge est capable de remplacer une partie importante de l'inertie essentielle au maintien de comportement adéquat de la fréquence et de la fiabilité des réseaux.

Mots clés : Inertie, comportement en fréquence, charge intelligente, réponse quasi-inertielle

1. Introduction

The instantaneous balance of power supply and demand is the fundamental reliability criterion of electric power systems. When an imbalance occurs, the system frequency deviates from its nominal value. Therefore, frequency control (the action of maintaining system frequency within a given tight range) is fundamental in order to provide a reliable and secure power grid. Traditionally, one of the main principles that supports the stability and reliability of the electric grid is to rely on large synchronous rotating mass in bulk generating plants to provide the inertia and governor response required for the electrical grid to manage most loading and transient events and to prevent adverse impact for the users.

The increasing penetration of renewable energy production such as wind power and solar photovoltaic, distributed generation and other electronically coupled resources combined with the decommissioning of large coal and nuclear power plants introduces new challenges in electrical power system particularly due to their well-known inherent intermittency.

Apart from their intermittent nature, most of 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.

Power system inertia is vital because it determines the sensitivity of the system frequency towards supply demand imbalances. For example, with less power system inertia, the frequency is more sensitive to temporary imbalances. Inertia is the instantaneous response that is automatically self-deployed from synchronous machines following disturbances and consequently become a key determinant of the strength and stability of the power 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 have become a major concern and an important design constraint mainly because there is very little way to change or control the initial rate of change of frequency (RoCoF) and the frequency nadir. There is therefore a growing need to assure the provision of a sufficient amount of inertia and many power systems (ex: Ireland [1], Texas [2], Hydro-Québec [3], New Zealand [11]) are reviewing their grid code to ensure that their inertial response is adequate.

Load is technically capable to assist in the balancing of the power grid and its frequency control. By modulating the load, it is possible to provide reliability services such as inertia and primary response that are the most technically challenging services to be supported.

Altogether, 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. Section 2 gives an overview of Frequency response and mechanism involved in its control. Concerns with frequency response in power systems with high levels of Renewable energy penetration are discussed in section 3 and 4. The main characteristics required for load to provide fast frequency response is discussed in section 5 and 6.

Section 7 and 8 highlight through time domain simulations how power system frequency response, frequency RoCoF and nadir can be improved by the deployment of Dynamic and Continuous Load Controller. Lastly, section 9 shows some test results coming from prototype installed in real conditions.

2. Frequency response overview and new threat to power system reliability

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

Following an event involving a generation-load imbalance, frequency control can be roughly divided into two overlapping phases. In the first phase, inertial response and primary response (essentially governors) arrest and stabilize the frequency decay. In the second phase, the frequency is restored to its nominal value by Secondary (AGC) and Tertiary (mostly off-line generation) response.

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 size of the resource loss and the inertia of the system determine the slope of the frequency decline (RoCoF). Following this initial response, generator governors sense the frequency change and begin to adjust their input to increase the energy needed. Governor response speed depends on the type of turbine; the shortest response being provide by gas turbine, followed by steam turbine. The longest time delays are usually associated with high head hydro turbine that require long times until the supplementary mass flow throughout the turbine. The combination of synchronous inertial, turbine governors and load 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 has been arrested, frequency rebounds to the settling frequency (Point B in fig. 1) as the turbine governor deploy spinning reserve. The system frequency then stabilizes at an off-nominal frequency in which the system is still vulnerable.

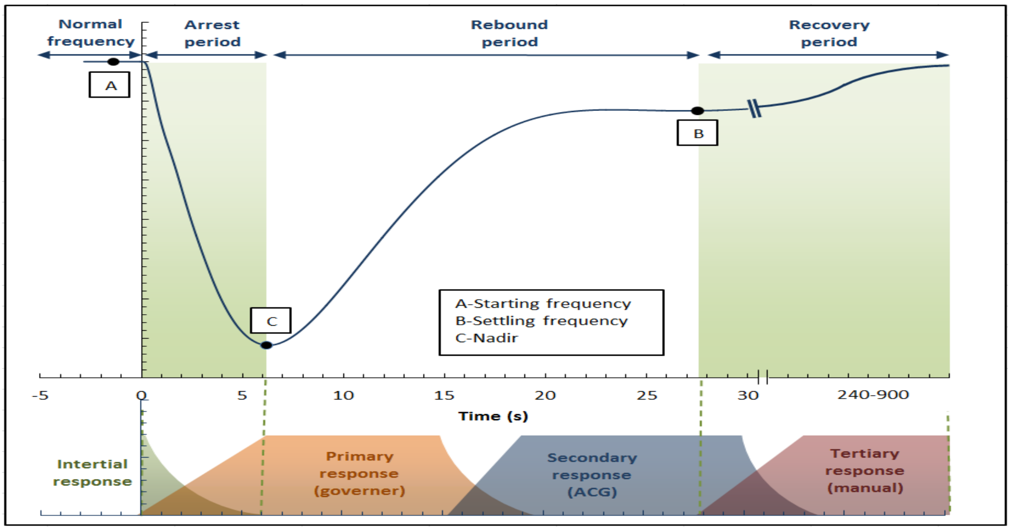


Figure 1: Illustrative frequency response after the loss of a generation unit

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 service, replace the Primary and Secondary resources and reestablish the power system ability to counter another contingency.

To be reliable, power system frequency must be operated between strict limits before and during an event. Power systems around the world have different defined standards of frequency behavior which all connected equipment must be able to support without tripping.

Under Frequency Load Shedding (UFLS) is a universal measure that automatically shed firm load to restore generation-load balance and protect the power system against a blackout if the frequency exceeds these normal operating ranges.

The threat to power system reliability that comes from loss of generation resources is the possibility that credible (or frequent) contingencies trigger tripping thresholds for frequency sensitive equipment (generators, electronically-coupled equipment or load) or initiate the UFLS system and shed firm load. High RoCoF can also trigger generator's RoCoF protection (often used as an anti-islanding protection on distributed generation) tripping additional generation and leading to cascade tripping and eventually to blackouts. The threat to reliability is more important in the first phase (Inertial and primary frequency response) of the frequency response than in the Secondary or tertiary frequency response period.

As a reminder, generation loss is the most common event in a power system. For example, the ERCOT power system encounters about 70 generation loss larger than 450 MW per year [4] and on average 10 events resulting in loss of firm load are experienced per year in US [5].

3. 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 operators 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).

As explained in section 2, power system synchronous inertial response has significant implications on the rate of change of frequency (RoCoF) and frequency nadir during power imbalances. By increasing non synchronous generation, power system synchronous inertial response is reduced and RoCoF increases, leaving insufficient time for governors to deploy and arrest system frequency decline before nadir hits UFLS or equipment tripping settings (i.e. time between point A and C, Figure 1). Therefore, there is a major concern to assure either a provision of a sufficient amount of inertial response or a sufficiently prompt action from primary response on power system with high level of INSP.

The main reliability threats of reduced power system inertia or slow primary frequency response are then:

- The steepness of the RoCoF that could cause equipment tripping.
- The short time delay before frequency nadir is reached that puts pressure on the primary control time response to avoid Under Frequency Load Shedding.
- The duration to which frequency remains near its nadir that requires an adequate and sustained governor action to create a rebound and initiate the frequency recovery.

4. 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 total system response to an initiating event is determined by the summation of the contributions from each of the online 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.

The release of energy from a load or a storage resource can be controlled independently and can even deliver a larger amount of energy than the imbalance. Therefore, it could easily compensate the time delay associated with the controlled action. Said otherwise, *inertial frequency response of synchronous machine could be replaced by controlled actions. From a reliability point of view, it does not matter if the energy required to maintain generation-load balance comes from synchronous source, demand response, or storage as long as the providing source responds with the speed and magnitude that is required.* The characteristics of concern for Quasi-Inertial Response are the range of control (in MW), the ramping speed (in MW/min), the response accuracy and the response duration.

Requirements for an ideal quasi-inertial resource are then a continuous and proportional response (like governor), a high MW range, a fast and accurate ramping capability and a sustained response that will not negatively impacted the governor response by a premature withdrawal. This quasi-inertial resource will then be able to replace inertial frequency and governor response (primary frequency response).

5. 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 in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times 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 have not typically been used for reliability response.

More recently, demand response has begun to be considered to directly supply reliability services to the power system. Using load to provide reliability service such as spinning reserve requires a fast but short duration response (<10 minutes). Also even if response is only required during a power system event, response must always be available.

Quasi-inertial response can easily be supplied by certain loads because (in many cases) they are able to provide a near instantaneous response; the speed of the response being only limited by the electronic controls used to activate the desired response. For example, all domestic resistive loads (electric water heater, electrical heating and dryers) have no physical constraint toward the rapidity of the response and could nearly instantaneously change their power consumption. These loads can be rapidly modulated, restarted and are even ready to immediately respond again should another contingency arise. Loads could then provide a response with a higher reliability value than generators (including wind synthetic inertia) with time delays required by the physics of the turbine-generator.

Quasi-inertial response is particularly well suited for electric loads that are not sensitive regarding the moment when their energy is needed. For example, reducing the portion of the energy supplied to a water heater or air-conditioning during a few minutes will have little incidence on the hot water or room temperature (because of the thermal inertia) and will be imperceptible to the user.

Characterizing and identifying physical limitations and operational issues of loads are keys to successful participation of loads in quasi-inertial response characteristics that are acceptable to the load. A large number of load types have the capability to provide quasi-inertial response as it is shown on Table 1.

Residential	Commercial	Industrial
Hot water heaters	Warehouse refrigeration	Aluminum plant
Heating baseboard	Air conditioning	Data center
Air conditioning	Heating	Variable speed motor drive
Electric vehicle	Lighting	Pumping system

Table 1: Examples of load capable of providing quasi-inertial response

6. Dynamic and continuous load controller (DCLC) main characteristics

Under frequency load shedding shed firm load when frequency stability is jeopardize and is used by utilities around the world as a last line of defense against frequency events. However many loads can provide reliability service (like spinning reserve or regulation) without compromising customer service [9]. It has been demonstrated [10] that an aggregation of a large number of small controlled loads has the potential to participate to the frequency protection of the power system and to provide frequency support after a frequency event. The concept of DCLC is simple: one needs to install a continuous and rapid load regulator that has two mains functions; it reads the frequency and automatically and autonomously modulates the power consumed by this load. The aim: quickly compensate for the lack of power system inertia and improve the power system frequency behavior (like an unconstrained and ideal turbine governor).

Systemex Energies has designed and developed a Dynamic and Continuous Load Controller (DCLC) to improve frequency response (mainly inertia) usually supplied by synchronous generators. This development is based on Systemex patented Soft-R^3 ™ platform, a grid friendly product developed to provide a wide range of reliability service like spinning reserve or regulation as well as solutions for grid with intermittent power generation or high ramp up problem.

As an automated demand response product, DCLC is a device installed directly on loads (ex. electric water heater, storage heater, air conditioner or electric vehicle) to regulate the power consumption based on the power system frequency behavior. DCLC distinctive factors as a quasi-inertial frequency controller are:

- **Fast acting**: Rapidity is the main requirement to supply quasi-inertial reliability service. With a speed of reaction down to 35 msec and its control strategies, DCLC is able to anticipate grid frequency behaviour allowing immediate and predictive response which can compensate for the negative impacts of reduced power system inertia. Well-chosen loads (like water heaters) present no particular constraint and can provide an immediate response with a higher reliability value than governor or wind turbine emulated inertia. This is because, unlike turbine-generator physics and mass flow, there is no time delay associated with the load providing the power and energy reduction.
- **Continuous control**: Unlike ON/OFF and other step technologies, DCLC is an autonomous, continuous and proportional controller. It could be seen by a power system operator as the "perfect" turbine governor. The main advantages of continuous control over ON/OFF or step controller are that it is: predictable, flexible, and robust against any frequency behaviours. Similarly to turbine governor, continuous load control allows deployment without having to change the settings regardless of changes in frequency response behaviour overtime and requires no telemetry and no direct action to perform its basic actions as a quasi-inertial frequency controller.
- **Innovative control strategies**: Control strategies developed by Systemex Energies are completely user customizable allowing linear, nonlinear as well as the usual droop control strategies used in all power systems. Moreover DCLC can be set almost exclusively according to power system performance and is fully configurable unlike governor or wind turbine emulated inertial response. It can therefore be adapted to solve most of the problems related to frequency behaviour in power systems.
- **No negative interaction with other power system elements**: DCLC action is faster but similar to the action of current governor droop strategies. With its efficient control strategies its action is fully coordinated (as the turbine governor are) with all grid equipment and systems (static excitation, power system stabilizer, governor, static or synchronous compensators, series compensation) or other special protection systems (UFLS) that can be found in power system.

7. 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.

In this demonstration, the following power system conditions are used to investigate the effect of synchronous inertia on frequency response:

- A peak load power system of 30 GW with 1000 MW of spinning reserve and with 126 GMVA-sec of system inertia.
- A light load power system of 18 GW with 2600 MW of spinning reserve.
    - First case with only conventional generation and 88 GMVA-sec of system inertia.
    - Second case with 9 GW of conventional generation and 9 GW of wind turbine (50% INSP) and 44 GMVA-sec of system inertia.

These conditions represent well-known situations in power system: a peak load condition with maximum daily value, spinning reserve minimal but synchronous inertia at its maximum, and a light load condition with a robust system with resources availability not restricting spinning reserve but with synchronous inertia at a lower value.

For the purposes of this study, the power system frequency design objectives were set as follows:

- Largest single contingency: 1000 MW.
- Minimal spinning reserve: 1000 MW.
- Minimum frequency before UFLS: 58,8 Hz.
- Maximal allowable RoCoF: -0,50 Hz/sec.

This last criterion is used to demonstrate the ability of DCLC to ensure adequate frequency behavior with a specific RoCoF target when the inertia of the system is reduced.

8. 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.

8.1 Effect of inertia on power system frequency response.

Figure 2 compares power system frequency response for the tripping of a 1,000 MW generator in the three different following situations:

- Blue curve: loss of 1000 MW of generation, peak load condition, total system inertia 126 GMVA-sec.
- Red curve: loss of 1000 MW of generation, light load condition, total system inertia 88 GMVA-sec.
- Black curve: loss of 1000 MW of generation, light load condition with INSP of 50% total system inertia 44 GMVA-sec.

From curves comparison it is straightforward to observe how frequency response is changed for the same generation loses with different inertia. It is clear that when system inertia is lower, the same generation loss creates a much steeper and deeper frequency excursion. The displacement of 9 GW of conventional generation by 9 GW of wind generation in the light load case (black curve) only acerbates this natural tendency.

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.

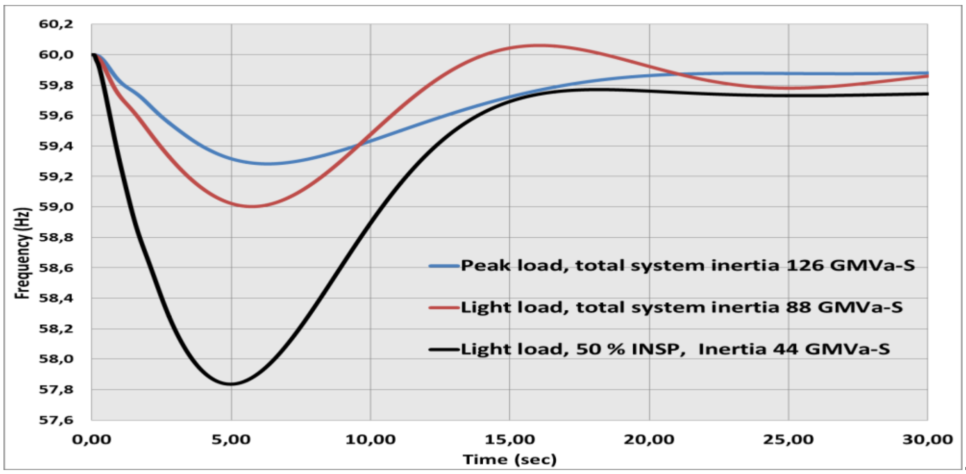


Figure 2: Comparison of frequency response for loss of 1000 MW in peak load and light load conditions

Note that in light load condition (red curve), spinning reserve (2600 MW) is more than two times the generation lost (1000 MW). The power system has then the ability to properly control the frequency and cope with the loss of 1,000 MW but during the initial seconds of the disturbance event, the primary frequency response from the turbine governors has not yet influenced the frequency decline because of times delays associated with governor actions. This raise out the importance of a fast action on the initial frequency behaviour and nadir.

Power system condition	Total system inertia GMVA-s	DCLC max (MW)	Frequency nadir	RoCoF
Peak load	126 GMVA-s	-	59,3 HZ	-0,15 Hz/sec
Light load	88 GMVA-s	-	59,0 HZ	-0,30 Hz/sec
Light load with 50% INSP	44 GMVA-s	-	57,8 Hz	-0,70 Hz/sec
Light load with 50% INSP, DCLC 1	44 GMVA-s	450 MW	58,9 Hz	-0,47 Hz/sec
Light load with 50% INSP, DCLC 2	44 GMVA-s	600 MW	59,2 Hz	-0,30 Hz/sec

Table 2: Frequency nadir and RoCof for different situations

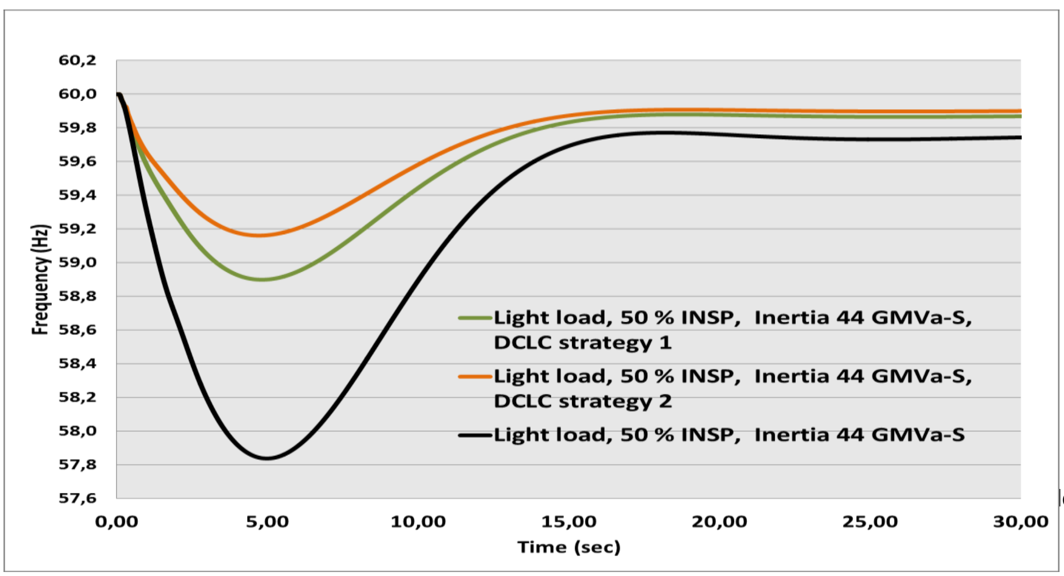
8.2 Effect of DCLC controller on RoCoF and nadir

This section highlights the effect of the new DCLC controller on power system frequency response when it is adjusted to control RoCoF. The control philosophy used here as a quasi-inertial response, is a mix of the usual 5% droop and a predictive algorithm that allows a faster response when RoCoF becomes too high. This strategy can be adjusted more or less aggressive depending on control objective and specific power system characteristics. Because the DCLC is a continuous regulator, the amount of load modulation is not set point fixed (like in On/Off system) but is taking within an 800 MW pool. The control strategy automatically adjusts the load modulation to achieve the specific frequency response performances and targets.

Figure 3 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.

The following conclusions can be easily drawn from the comparative analysis of the three curves in Figure 3 and from Table 2.

1. The effect on frequency response is drastic. DCLC is able to change the RoCof and the frequency nadir and compensate for the reduced power system inertia. DCLC is able to ensure that the system frequency is maintained within the fixed RoCof and nadir limits.
2. Another key point in Table 2 is that 450 MW of modulated load could completely compensate the reduction of the grid inertia created by the replacement of 9000 MVA of conventional generation by wind generation. In other words, 450 MW of DCLC is as effective in controlling RoCoF as 9,000 MVA of synchronous machines.
3. It is clear that frequency response is improving (both RoCoF and nadir) with the second DCLC strategy. It takes only an additional of 150 MW of modulated load once deployed to bring back RoCoF from -0,50 Hz/s to -0,30 Hz/s. It is clear that with sufficient MW pool, DCLC is able to regulate and control frequency response.



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9. Test results

As mentioned in section 6, Systemex Energies patented innovation based on Soft-R^{3} ™ platform, offers a grid friendly product developed to provide a wide range of reliability service like spinning reserve, 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-R^{3Tm}.

This major project has confirmed the ability of the Soft-R^{3TM} 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-R^{3TM} control strategy is adjusted to provide spinning reserve once the device is installed on an electric water heater.

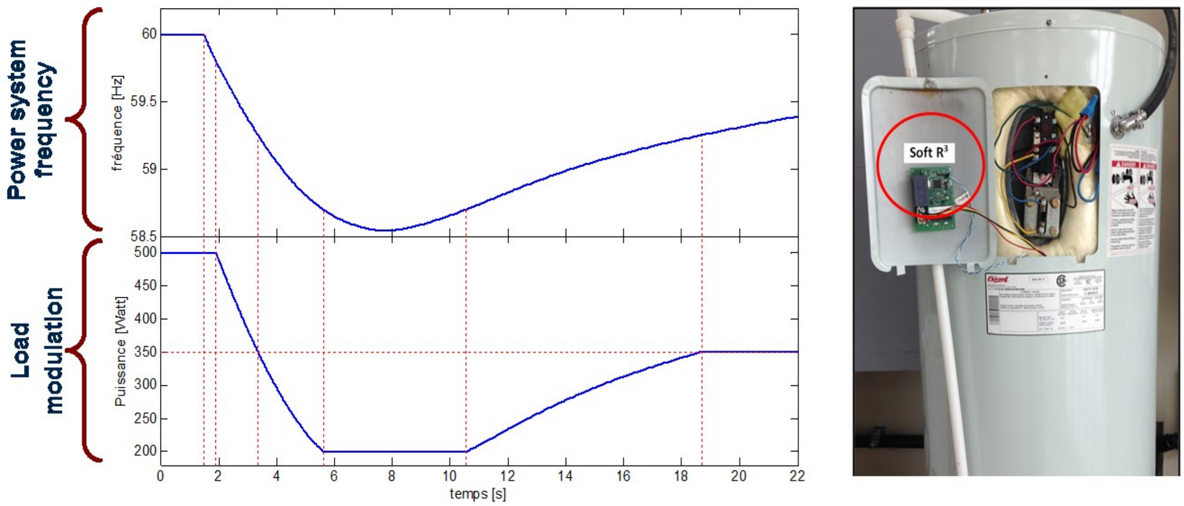

Figure 4: Frequency variation and load modulation for a Soft-R3 installed on a domestic water heater

10. Conclusion remarks

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 can be seen as a perfect 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).

This paper clearly demonstrated that DCLC could change the overall behavior of the frequency response, the RoCoF, the nadir and the damping. The future grid frequency can therefore be the result of a technical economic trade-off rather than a constraint to meet in the design of future power grids facing high penetration level of non-synchronous renewable resources.

If dynamic and continuous load control is successful, the benefits are considerable: A more efficient and stable power grid, cost reduction of renewable energy and removal of some of the barriers to integrate a higher proportion of renewable energy.

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12. Biography

Gilles Trudel worked for Systemex Energies, a Canadian holding company established in 2009 and created for the purpose of investing in and developing clean technology namely a Grid Friendly Device, trademarked Soft-R^3 technology. Before that he worked for more than 32 years in Hydro-Québec Transmission System Planning department where he was mainly involved in the design of the 735 kV systems, integration studies of large hydroelectric and wind plants and design of new control system to improve HQ power system reliability.

Simon Jasmin, Systemex Technologies Director, has over 17 years of experience in both technical and management of engineering and research and development projects. Some of its main activities cover the following areas: Research and Development projects of technologies related to energy and energy efficiency, design and modeling of processes and engineering related to industrial applications. He was responsible for the design, development, testing, demonstration and implementation of several technologies including Soft-R^3.