# Contribution to Electrical System Inertia of Dual Fuel two-stroke Engines in Isolated Grid: a Case Study

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**Abstract.** The paper analyzed the dynamic performance of dual two-stroke engines with respect to classical Diesel gensets and the contribution to increase the rotating inertia of an isolated electrical grid with significant penetration of Renewable Energy Sources (RESs). The role of genset capable to provide better inertia and primary frequency regulation is essential for the integration of renewable generation in order to provide frequency stability and better power quality.

## 1 Introduction

Isolated grids are systems characterized by low inertia, so they are more affected by frequency oscillations due to load variations. Additionally, sustainability policies are aimed to increase the share of RESs with respect to fossil energy sources [1]. This condition leads to increase the residual load, which is defined as the difference between actual power demand plus the feed-in of RESs and the power generation from dispatchable units [2]. This has a stressful impact on fossil energy sources in terms of stability since they have to meet a more variable power profile. Furthermore, RESs are typically inverter-connected generating units, hence, they do not provide any contribution to the electrical system inertia. It is well known that a perturbation in a low inertia system has more relevant consequences on frequency that in a system with large inertia. To deal with this problem, some papers propose the introduction of storage-based energy sources (Battery Energy Storage System (BESS) and pumped storage) to emulate the inertia contribution to frequency regulation. In this paper, the main target is to replace the existing dispatchable generators with new machines characterized by larger inertia so that the frequency oscillations are damped. Also, the authors propose a process for the verification in simulated field of model of synchronous generators to analyse its performance during normal operating conditions in the regulation of the system frequency through inertia. The island "La Palma" of the Canary Islands is chosen as case study, where the electric power system condition is similar to the one just described.

## 2 Context

Island La Palma is part of the Canary Islands archipelago. Its energy system is characterized by a peak demand of 43 MW [3]. On the side of the supply, the generation system is composed by two types of conventional technologies (Diesel engines and gas turbines), which represent almost 90% of the installed power, whereas RESs only represent 10% [4]. Despite the small installed capacity of RESs, a penetration of over 11% of renewable share was achieved in 2015 [5]. A simplified model of La Palma transmission system has been implemented in DIgSILENT PowerFactory environment [6], as shown in Figure 1.

**Fig. 1.** La Palma simplified transmission network model.

The transmission network is at 66 kV voltage level and its main areas are the primary stations of Los Llanos, El Mulato and Los Guinchos where the main fossil power plant is located.

## 3 Model

This paper discusses the performance of a new generation model with the aim to increase the power system stability of La Palma. Obviously, the study can be applied to any low inertia system. The proposed model is a dual fuel two-stroke engine, whose main parameter are reported in Table 1. It is worth noting that the number of the machine pole pairs can be inferred equal to 18 starting from the machine rated speed. Also, the relationship between the inertia constant and the corresponding moment of inertia, expressed in $kg \cdot m^2$ is reminded in the following equation.

$$\begin{cases} J = 2H\frac{S_n}{w_{ref}^2} \\ w_{ref} = \frac{2\pi f}{p} \end{cases} \quad (1)$$

where $S_n$ is the machine rated power, $w_{ref}$ is the rated speed, expressed in rad/s, f is the nominal frequency and p is the number of pole pairs. From Eq. (1) it is clear that a larger number of pole pairs corresponds toa higher moment of inertia. The generator is paired with a prime mover which is the subject of the tests. This model has been provided by WINGD [7]. To implement the model and simulate its dynamic performance in DIgSILENT PowerFactory, the control system of the generator, including the governor and the excitation system, is modelled as shown in Figure 2.

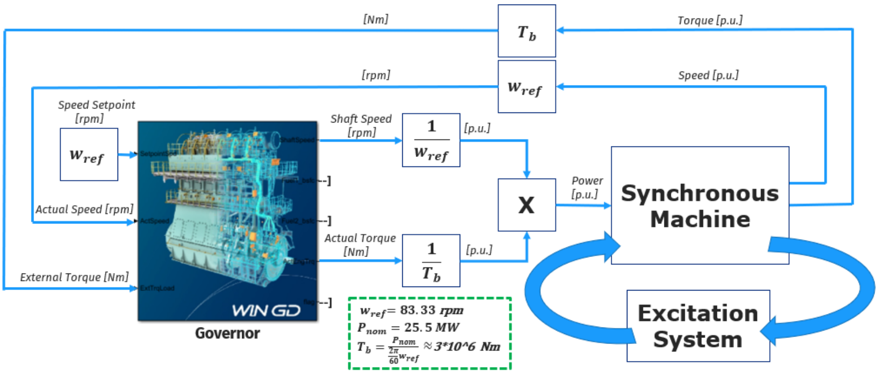

**Fig. 2.** Generator control system scheme, interface between synchronous machine and governor and the excitation system.

The governor model inputs are the machine actual rotor speed, its reference speed $w_{ref}$ and the external torque demand setpoint. The excitation system is a standard EXAC1 type [8]. For a better representation of the results, a benchmark generator model is implemented in a similar manner of Figure 2 to compare the dynamics of the two machines. The benchmark model main parameters are reported in Table 1.

**Table 1.** Generator model main parameters.

| Parameter | Proposed model | Benchmark model |
|---|---|---|
| Rated capacity [MVA] | 30 | 18 |
| Rated power [MW] | 25.5 | 14.5 |
| Rated power factor | 0.85 | 0.8 |
| Rated terminal voltage [kV] | 11 | 11 |
| Rated speed [rpm] | 83.3 | 3000 |
| Inertial time constant [s] | 2.603 | 2 |

The benchmark model has one pole pair, related to its rated speed, and it is paired with a DEGOV1 type governor [9]; this model does not coincide with the real engine used in La Palma, but it has similar performances in terms of stability after load change events. The excitation system, namely the Automatic Voltage Regulator (AVR), is not part of the study and the same type is applied to both models in order to focus on the prime mover effects on the machine dynamics; nevertheless, it can be also replaced with a new model for future analysis.

# 4 Verification

For the verification of any generating unit performances, the reference ISO 8528-5 2005 [10] defines three classes of generators depending on their capability of keeping the frequency nominal value and restoring it after a perturbation. The maximum transient frequency deviation is the maximum error from the nominal value that frequency can have after a 100% load step variation event, expressed as percentage of the nominal value. The frequency recovery time represents the time interval between the departure from the steady-state frequency band after a sudden specified load event and the permanent re-entry of the frequency into the specified steady-state frequency tolerance band. For a better representation, Figure 3 shows, for each generator class, an example of the frequency profile when a 100% sudden demand power increase occurs.

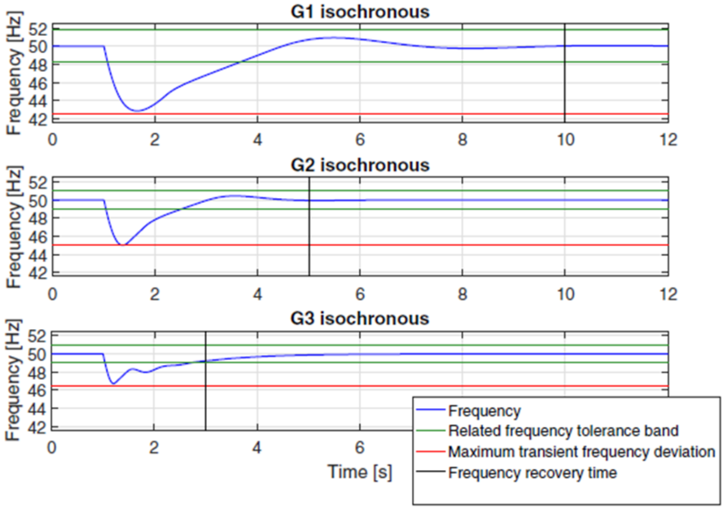

**Fig. 3.** Characteristics of generator classes G1, G2and G3.

The generator class G3 is the most effective in frequency regulation. For classes G1, G2 and G3 in a 50 Hz system, the maximum transient frequency deviation is 7.5, 5 and 3.5 Hz, respectively, while the related frequency tolerance band is 1.75 Hz for class G1 and 1 Hz for classes G2 and G3. In the first test for the model verification, a 100% step load event is simulated for both model generator, this represents the most extreme power variation. The transient response with both models is analysed observing the maximum transient frequency and the related frequency tolerance band in Figure 4.

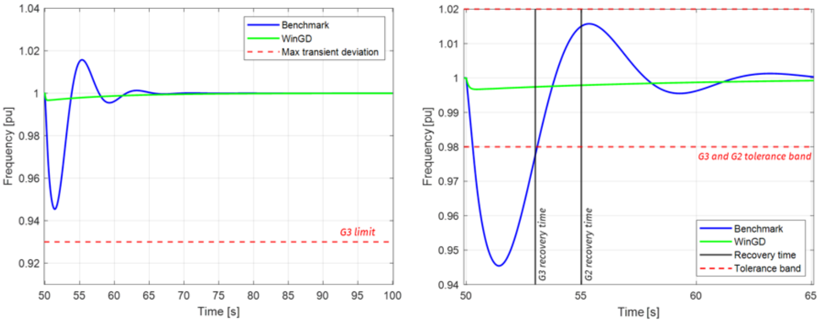

**Fig. 4.** Transient frequency after event, focus on G3 class maximum transient frequency deviation and G2 and G3 related frequency tolerance band.

The event is set to occur at 50 seconds from the simulation start so that the model can reach steady-state conditions when the event occurs. Result shows that both models satisfy the maximum transient frequency deviation requirement for G3 class, but the proposed model performs a better trajectory with respect the benchmark model. Observing the related frequency tolerance band, the benchmark model is a G2 class, because frequency is not restored before the G3 class recovery time; the proposed model meets the G3 class requirements as the frequency signal never violates the related tolerance band.

## 5 Test

To apply the proposed generator model to the Palma power transmission network of Figure 1, the largest machine, paired with standard DEGOV1 governor and EXAC1 AVR, has been replaced with the proposed model. After a simulation of 3000 seconds duration, the system frequency obtained with the two models is registered in Figure 5. Results in these figures clearly shows the better dynamics of frequency against load oscillation during normal operating conditions when the proposed model is active. Load oscillation profile is obtained by modelling the variations of the machine power demand, intended as the sum of variations from load and RESs. The difference between the two simulations represents the inertia contribution introduced with the new model. Evidence that the values of the frequency are more concentrated around the nominal value of 50 Hz is given in the figure where the frequency profiles in both cases are expressed as Probability Density Functions (PDFs). The frequency PDF with the traditional generator model has a variability of ±0.02 Hz and a peak value of 0.05. When the proposed model is active, the frequency PDF has a variability of ±0.005 Hz and a peak value of 0.085 proving a better frequency transient stability in the second case.

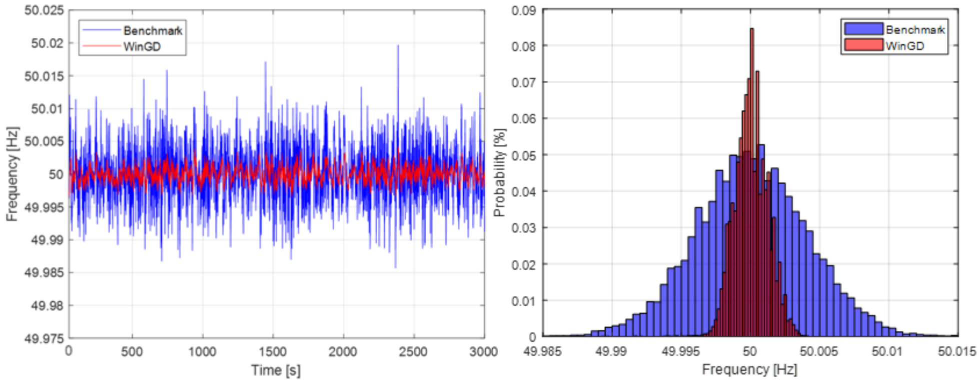

**Fig. 5.** Frequency profiles with disturbed demand applied to the study case, on the right the PDFs of frequency obtained with the benchmark model (in blue) and with the proposed model (in red).

## 6 Conclusion

In this paper, the performance of a governor model for frequency regulation is discussed, compared with a benchmark model whose parameters are known. For this purpose, some tests have been performed simulating a 100% load step variation to validate the model. After that, the final test is done by applying it to the transmission network of La Palma taking account the load oscillations in normal operating conditions. Results showed very good performance of the governor model which proved to meet the requirements of the G3 class generators, according to the standard ISO 8528-8 2005 [10]. The increase of frequency stability is evident when the proposed model is compared with the G2 class benchmark model. Moreover, the implemented software platform is performed such that the methodology applied in this paper to evaluate the governor performances can be repeated with new models so that more tests and comparisons can be carried out. This methodology can give information about the state of the power system if new technologies are employed, such as the quantification of new RESs plants that can be installed before violating the frequency constraints. The same concept can be adopted for the analysis of new AVR, models whose impact was not included in this study.

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