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Generator Fatigue Life Degradation Assessment (FLDA) Tool Manual

Demo Version 1.0

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Mechanical R&D

Generator Fatigue Life Degradation Assessment (FLDA) Tool Manual

R&D Documentation

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1. Introduction

The purpose of this document is to provide instructions on how to install the Edge Tune Power (ETP) Generator Fatigue Life Degradation Assessment (FLDA) model and link it to a case in PSCAD. This document also provides a high-level description of the functionalities and examples of the parameters.

Note: This document accompanies the demo version of the ETP Gen. FLDA. The demo version is for evaluation purposes only and shall not be used for any commercial purposes. The table below summarizes the features available in the demo and full versions.

Table 1 - Parameters Available in Demo and Full Version

Feature	Demo Version	Full Version
Analysis Window and Oscillation Characterization	✓	✓
Cumulative Damage Modeling	✓	✓
Common Power System Parameters	x	✓
Common Shaft Material	x	✓
Surface Finish, Loading Type, and Reliability Options	x	✓
Critical Point Diameter and Operational Temperature	x	✓
Commercial Use	x	✓

2. Installation Guide

Extract the provided zip file to your local directory. To run the model, you need to load the Blackbox to the resources tab of your case. Open PSCAD and then right-click on the resources file then navigate to Add and click on Source Code, as shown below:

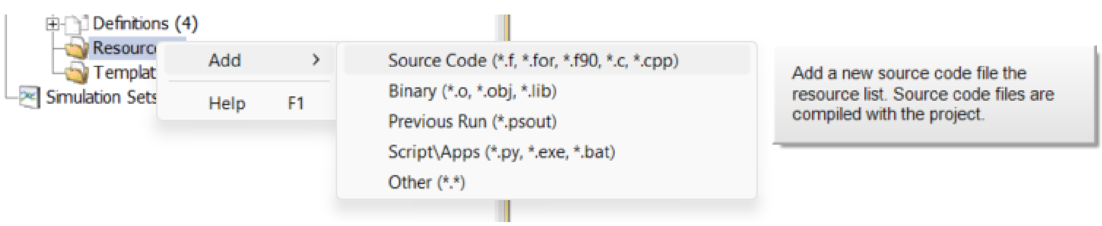

Figure 1 - Navigating Adding Resources on PSCAD

Open the "*ETP_FLD_Tool_V0_2_1*" folder in your extracted folder. Navigate to the bottom of the items and select "*Blackbox_ETP_FLD_Tool_V0_2_1.f*".

The tool is located next to the generator model in the test case. Double-click on the “SG” to open the generator model.

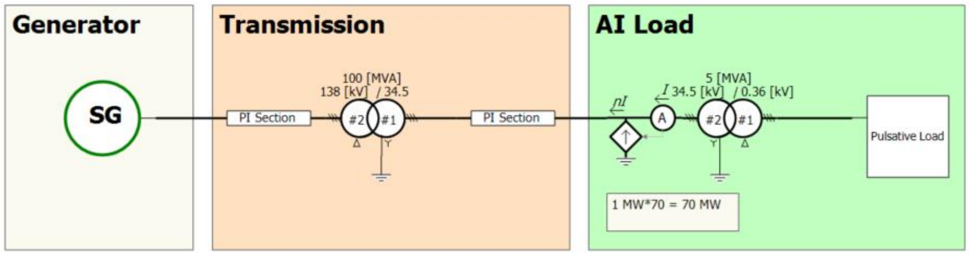

Figure 2 - Test Case First Page

3. Stress-Life (S-N) Method

Stress-life (S-N) is a common approach to estimate the lifespan of elements under oscillating loads. This empirical approach neglects the mechanism of fatigue and directly predicts the number of cycles to failure under a given oscillating load. The S-N curve, shown below, is generated from a large body of studies and shows three regions of lifespan given a constant reversible stress. These regions have low cycle and high cycle finite life, and infinite life.

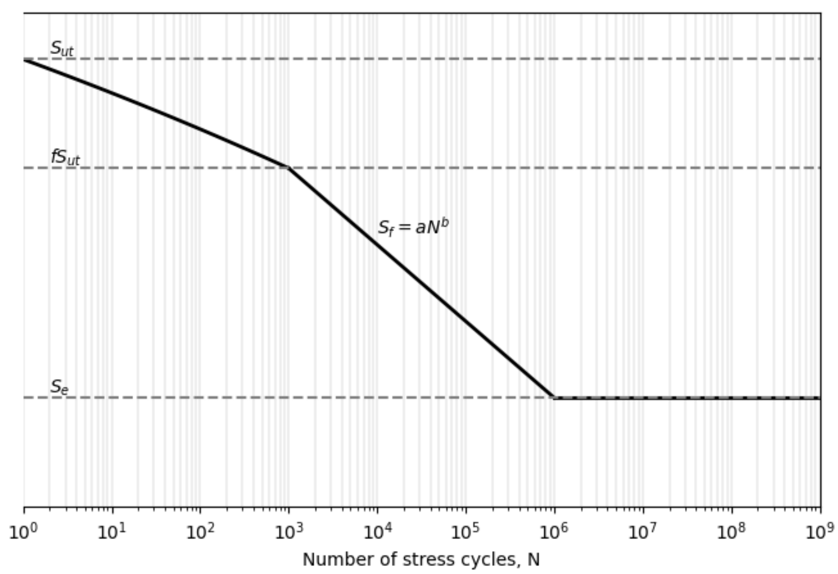

Figure 3 - The Stress-Life (S-N) Curve

The region of infinite life is at stresses below the endurance limit (S_e) of the material. Between the endurance limit and ultimate tensile strength (S_{ut}) multiplied by factor f, the machine element will have a high cycle finite life. Increasing stress will keep reducing the material until S_{ut} is reached, resulting in failure at one cycle.

4. ETP FLDA Model

The ETP FLDA model enables a high-level assessment of the lifespan of power generations systems. The model uses power system information and mechanical properties of the shaft to assess the damage of periodic oscillating loads and provide the lifespan of the system under the conditions specified.

4.1. Block Function

This model was originally designed to accompany a Sub Synchronous Resonance (SSR) simulation, enabling integrating lifespan impact assessment in PSCAD. The block directly connects to the critical torque (usually the shaft connected to the generator) and **outputs** the *impacted lifespan*, and the *endurance limit* and *f* factor of the shaft (both of which are used to regenerate the S-N curve, see previous section).

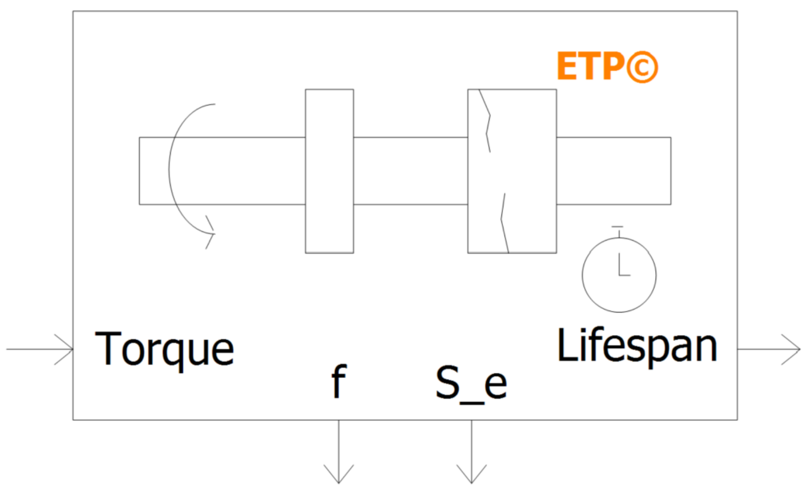

Figure 4 - ETP FLDA Block

SSR simulation critical torque data usually falls into three segments. The pre-SSR phase, transient SSR response, and SSR periodic steady state. To accommodate for these different phases, the user can input the time window that they are interested in (the periodic steady state) using the Model Configuration Window, covered in subsection 3.4. It's recommended to run the simulation once to see the torque response and then selecting the time window in which the system has reached periodic steady state.

As it's not expected that the system to operate in SSR conditions all the time (i.e. fast load variation expected during the AI training modes), the user can input the number of hours per month the system is expected to be subjected to SSR. This feature provides operational assessment and is also covered in section 3.4.

4.2. Block Process and Sample Setup

The process can be summarized as follows:

1. The block takes the signal from the torque output.
2. The signal is then characterized over the time window of interest, providing average values of signal amplitude, mean, and frequency.
3. Material properties are processes to evaluate respective values in the S-N model.
4. The lifespan degradation factor is calculated using the signal characteristics, S-N model, and baseline values provided. The modified lifespan is then reported.

Note: Steps 3 and 4 are only calculated once at the end of the analysis window whereas step 2 is executed alongside the simulation in the time window specified by the user.

The figure below showcases a sample setup, using the PSCAD Sub Synchronous Resonance (SSR) example. The signal used is the turbine-generator torque reading and is wired directly into the block.

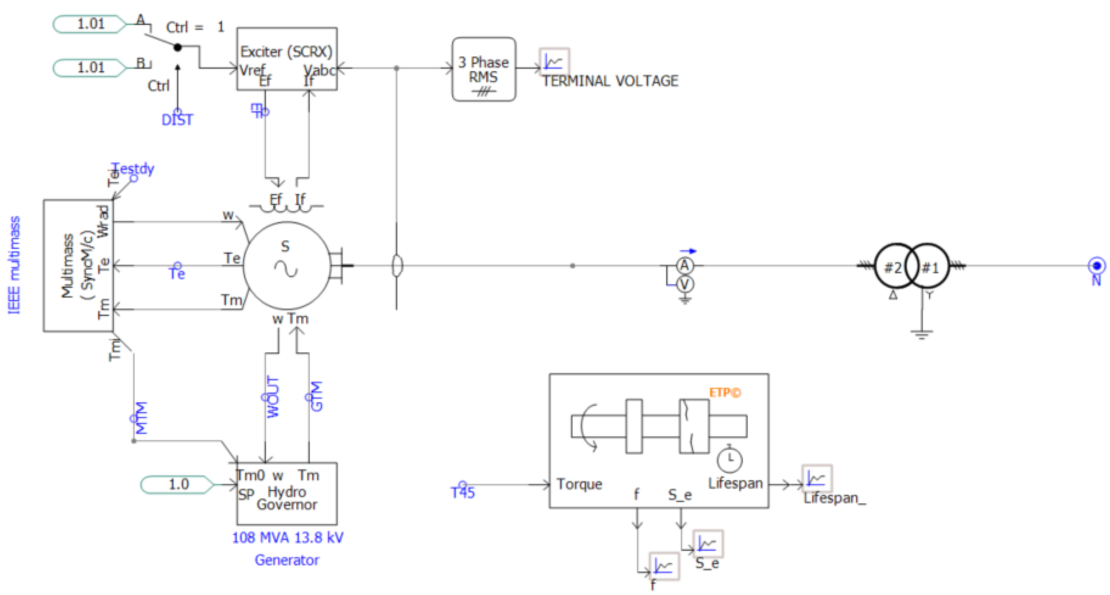

Figure 5 - Sample Setup

4.3. Block Parameters

Table 2 - All Model Parameters

Category	Parameter Name	Default Value [Range]	Unit
Configurations	Name	N/A	N/A
	Analysis Start Time [s]	10 [0, 1E+308]	s
	Analysis End Time [s]	20 [0, 1E+308]	s
	Hours of SSR per Month	2 [0, 720]	Hours
	Shaft Material	AISI 4340	N/A

4.4. Model Configuration

The user can configure the study using the following category. Right click on the block and select "Edit Parameters ..." to access the parameters menu.

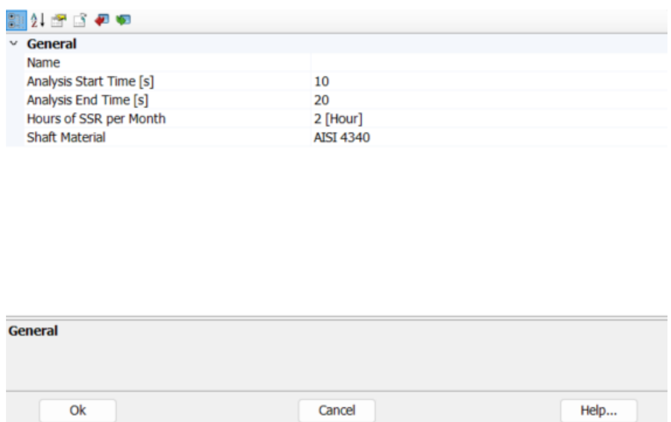

Figure 6 - Configuration Window

The analysis time window allows the user to select the portion of the critical torque data that represents the SSR periodic steady state. The user can select the start and end time using the *"Analysis Start Time [s]"* and *"Analysis End Time [s]"* parameters.

Note: It is highly recommended to run the study once to identify the time window of interest and ensure that the time window is sufficiently long to represent the profile.

The proportion of time the system is subjected to higher oscillations is selected via the *"Hours of SSR per Month"* parameter. The user can set this parameter to 720 if they are interested in the lifespan of the system only subjected to higher oscillations.

4.5. Model Settings

The demo version does not provide access to the following settings, static values are used as shown below:

Table 3 - Static Parameter Values

Category	Parameter Name	Static Value	Unit
Power System Info.	Rated Lifespan [Hours]	20000	Hours
	Rated Torque Ripple [%]	Gas Turbine (1%)	N/A
	Dominant Shaft Frequency [Hz]	50	Hz
Mechanical Properties of the Shaft	Shaft Material	AISI 4340 (IC Crankshaft, Gen. Rotor)	N/A
	Surface Finish	Machined or Cold-Drawn	N/A
	Diameter Unit	[in]	N/A
	Critical Point Diameter	2	N/A
	Loading Type	Torsion	N/A
	Temperature Unit	[°Celsius]	N/A
	Operational Shaft Temperature	150	N/A
	Reliability	99.9%	N/A

Appendix: Model Assumptions

The following assumptions have been made to enable this analysis:

1. The standard stress-lifespan model [1] of fatigue applies in the analysis of power system shafts. The system is designed for the finite high cycle lifespan.
2. The rated lifespan of the shaft is calculated using the S-N model with the rated torque ripple as expected stress amplitude on the shaft.
3. The mean stress is not changed in various studies. This assumption corresponds to the main application of this model to analyse Sub Synchronous Resonance (SSR).
4. The only loading type impacting the system is torsion and there is a linear relationship between the torque and maximum stress experiences by the shaft and its critical point.
5. The critical point of the shaft is not changed because of variations in torsion.
6. The equivalent reversible stress amplitude can be calculated using the Smith, Watson, and Topper (SWT) method [2].
7. The cumulative damage can be assessed using the Palmgren-Miner rule [2].
8. There are no significant notch effects.
9. The maximum stress does not exceed the limit where the lifespan of the shaft enters the finite low cycle lifespan.
10. The model assumes 24/7 operations of the system. The simulation results are reflected on the month scale and assume rated conditions otherwise.

References:

[1] R. Budynas and K. Nisbett, Shigley's Mechanical Engineering Design: 2024 Release Ise. OH: McGraw-Hill, 2024.

[2] N. E. Dowling, K. Siva Prasad, and R. Narayanasamy, Mechanical Behavior of Materials: Engineering Methods for Deformation, Fracture, and Fatigue. Boston, Mass, London: Pearson ; Pearson Education, 2013.