Modeling and Simulation of a Smart-Grid UFLS Relay Applied to the ONEE and SENELEC Networks

Birane Diaw

https://bdiaw.lovable.app/

Abstract— This report presents a system-level model of an under-frequency load shedding (UFLS) relay applied to two African grid cases: the ONEE interconnected system in Morocco and the SENELEC system in Senegal. The project combines aggregated frequency-power dynamics, droop-based primary control, secondary AGC action, and a timed-threshold Stateflow automaton. The simulations show that load shedding is triggered before frequency collapse and is automatically removed once frequency returns to the restoration range.

Keywords—Smart Grid, UFLS, load shedding, frequency, Stateflow, Simulink, transient stability.

I. Introduction

Frequency decline after a generation loss is one of the most critical mechanisms for power-system security. When primary reserve and natural damping are not sufficient to rebalance generation and load, an UFLS relay sheds a fraction of demand according to predefined thresholds. The aim of this project is to build a reproducible simulation bench able to compare two equivalent networks and visualize the automaton behavior.

II. Architecture and Dynamic Model

The grid is represented by an equivalent machine. Frequency is computed through an aggregated swing equation expressed in per-unit deviation around 50 Hz. The disturbance is a generation loss applied at t = 10 s. Shed load is subtracted from the active disturbance, which closes the loop between the UFLS automaton and the grid dynamics.

The governor follows a droop law with time constant Tg. The primary reserve signal is limited by P_gov_max, while AGC slowly integrates the frequency error to drive the system back toward nominal frequency. The automaton has six states: NORMAL, ALERT, SHED1, SHED2, SHED3 and RESTORE. Each shedding threshold is validated after a confirmation delay; restoration requires frequency to remain above f_restore for a minimum hold time.

III. Parameters and Scenarios

The parameters below are not official operator data. They are engineering assumptions selected to obtain comparable, stable and readable demonstration scenarios.

Table I. Main parameters of the two study cases.

Parameter	ONEE	SENELEC
S_base	11.0 GW	1.4 GW
P_load0	6.5 GW	700 MW
H	5.0 s	3.0 s
D	1.5 pu/pu	1.0 pu/pu
R	0.05 pu/pu	0.05 pu/pu
Tg	6.0 s	4.0 s
P_gov_max	0.15 pu	0.12 pu
P_loss	1540 MW	168 MW
f_alert	49.5 Hz	49.5 Hz
stage 1	49.0 Hz / 10 %	49.0 Hz / 12 %
stage 2	48.7 Hz / 15 %	48.6 Hz / 18 %
stage 3	48.4 Hz / 20 %	48.2 Hz / 25 %
t_confirm	0.30 s	0.25 s
f_restore	49.90 Hz	49.90 Hz
t_restore_hold	5.0 s	6.0 s
f_collapse	47.5 Hz	47.0 Hz

IV. MATLAB/Simulink/Stateflow Implementation

The project provides two simulation paths. The first one is a pure MATLAB loop used to run cases quickly, generate plots and perform validation. The second one generates real Simulink models with a Stateflow chart for the relay, allowing graphical visualization of states and transitions. The generated models are sf_ufls_onee.slx and sf_ufls_senelec.slx.

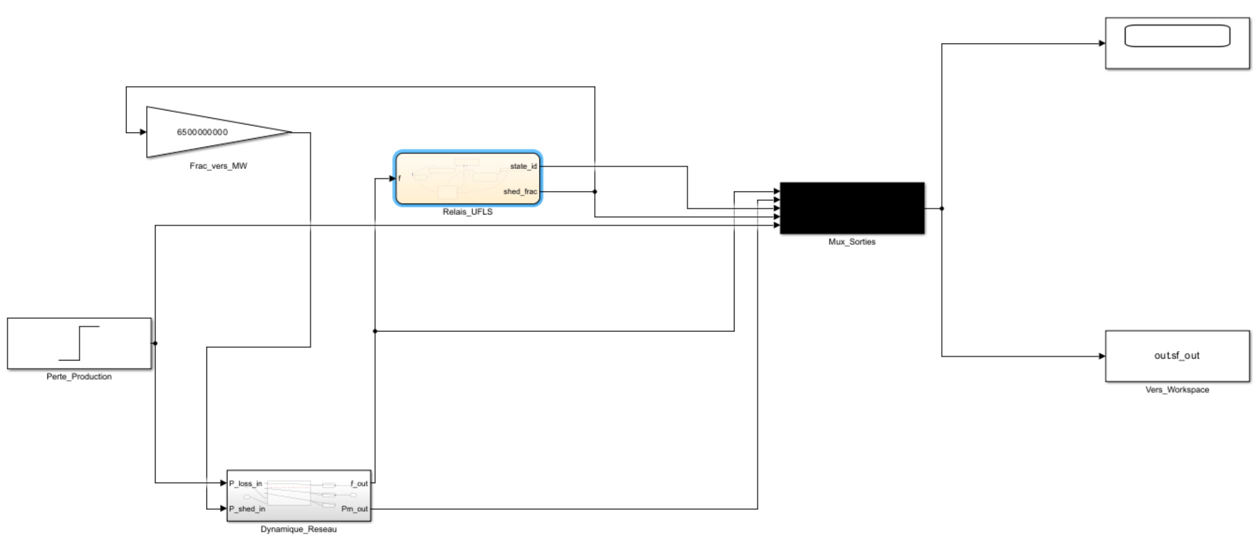

Figure 1. Generated Simulink model for the ONEE case, with a closed loop between grid dynamics and UFLS relay.

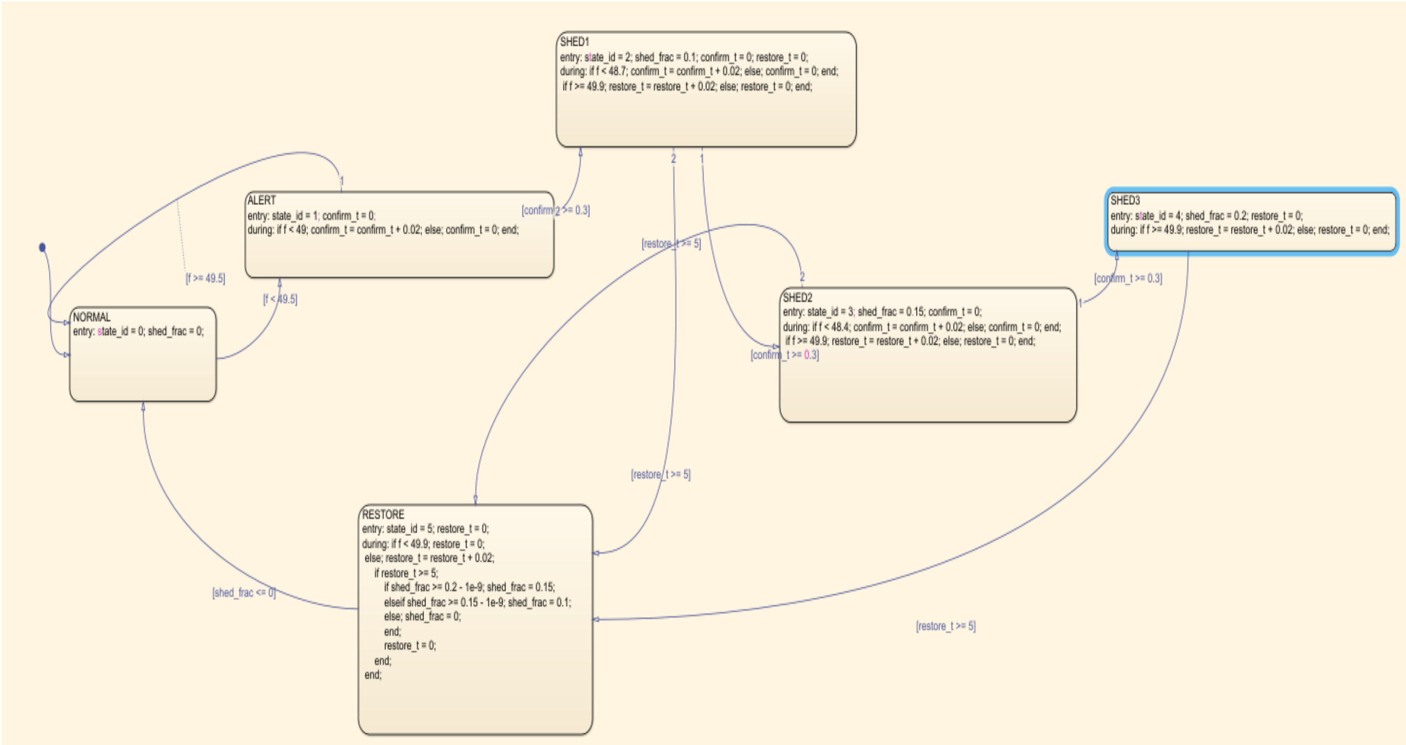

Figure 2. Real Stateflow chart of the UFLS relay, exported from sf_ufls_onee.slx.

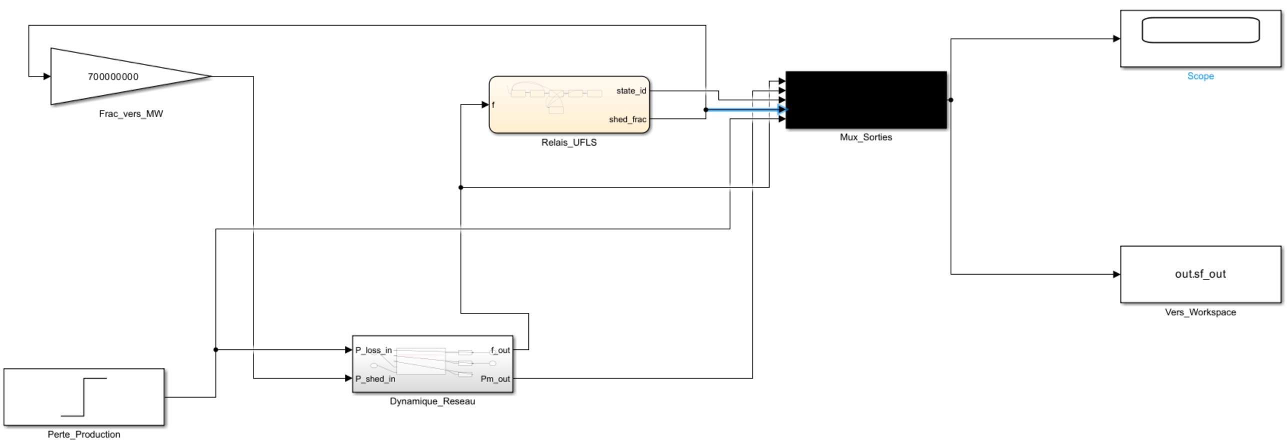

Figure 1. Modèle Simulink généré pour le cas SENELEC, avec boucle fermée entre dynamique réseau et relais UFLS.

V. Simulation Results

In both cases, frequency drops below the alert threshold and activates first-stage shedding. The governor response and AGC action then stabilize the system. Once frequency remains above the restoration threshold, the shed load is restored and the automaton returns to NORMAL.

Table II. Summary of simulated performance.

Case	Network	f nadir	t nadir	Max shedding	Final shedding	Collapse	Restored
ONEE	Reseau interconnecte ONEE - Maroc	48.956 Hz	12.38 s	10.0 %	0.0 %	No	Yes
SENELEC	Reseau interconnecte SENELEC - Senegal	48.983 Hz	11.78 s	12.0 %	0.0 %	No	Yes

The ONEE case applies a 1540 MW loss on a 6500 MW load base; the maximum shedding level is 10 %. The SENELEC case has a smaller base and lower inertia, but the selected thresholds and 12 % shedding also avoid the collapse threshold. The nadir remains close to 49 Hz in both scenarios.

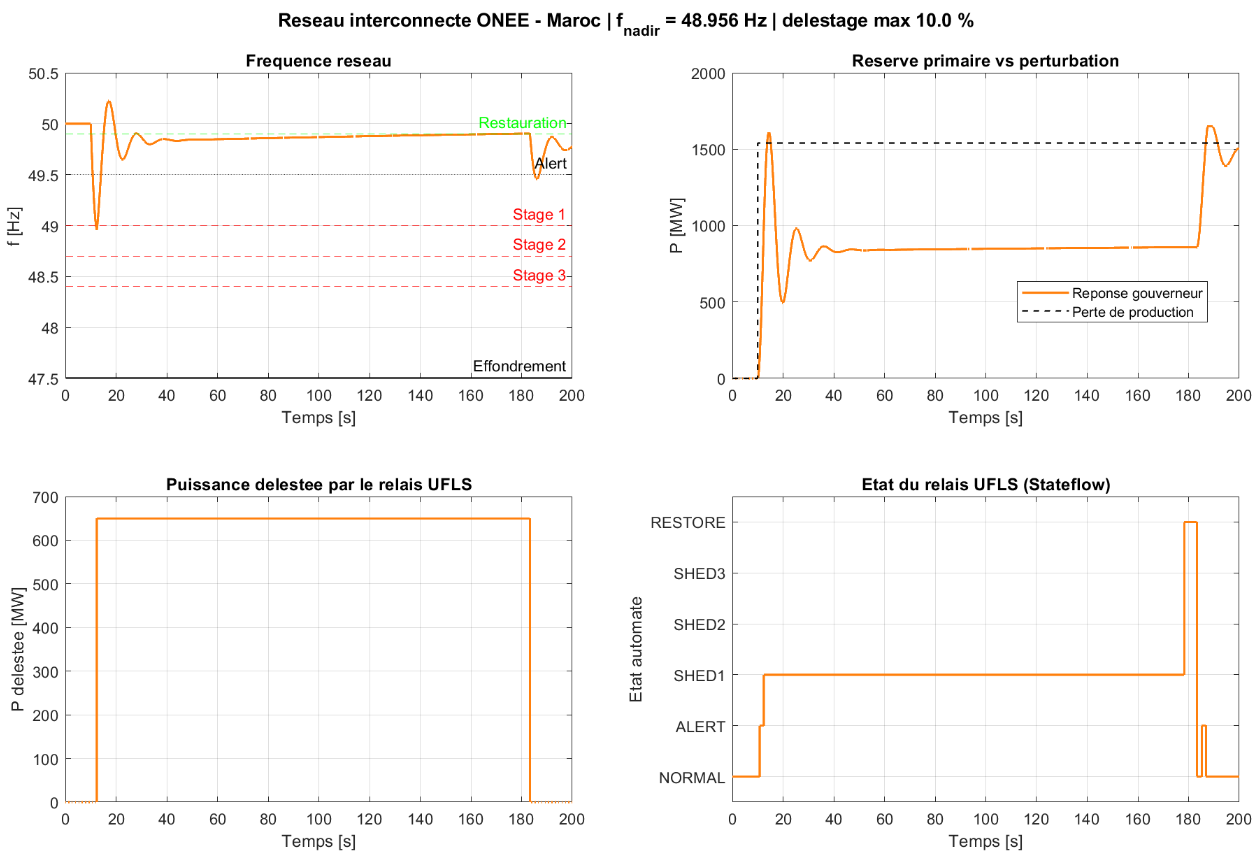

Figure 3. ONEE time-domain results: frequency, primary reserve, shed power and automaton state.

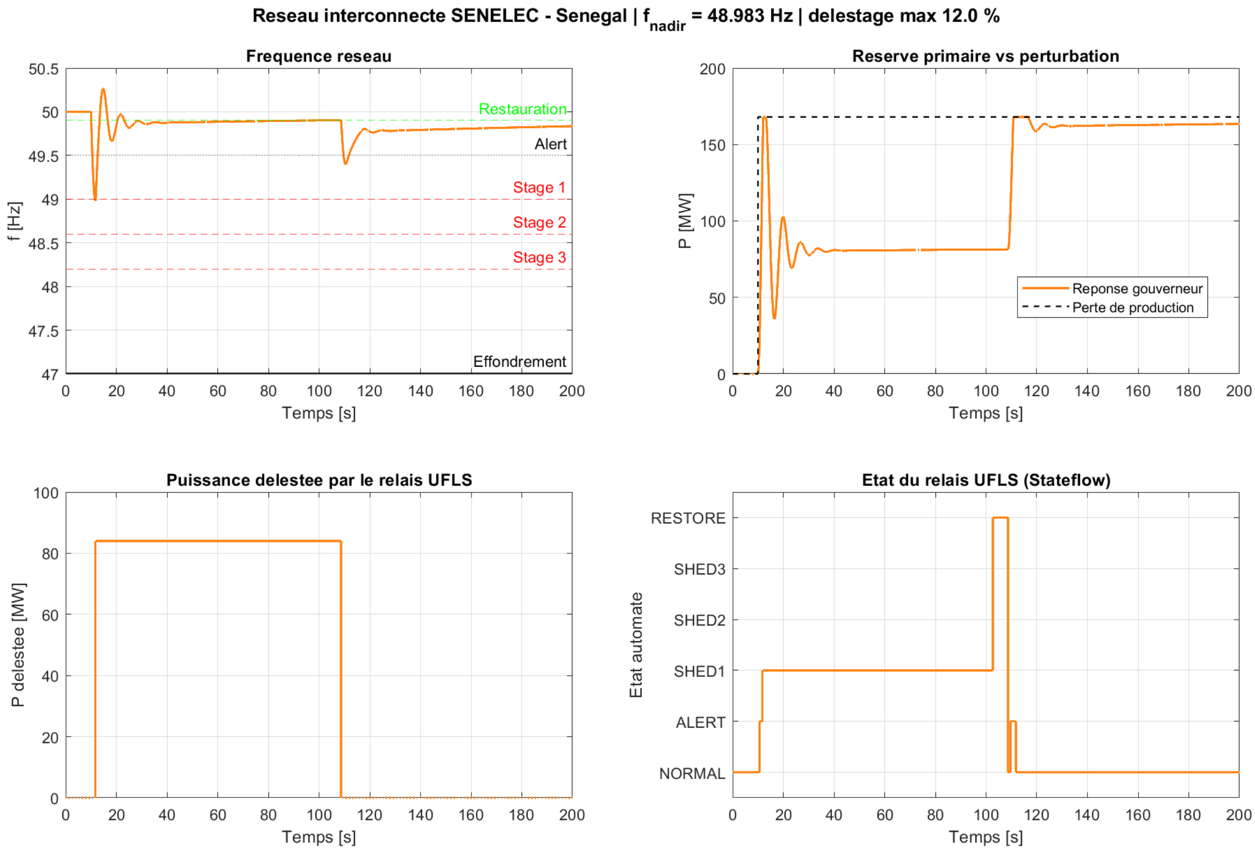

Figure 4. SENELEC time-domain results: frequency, primary reserve, shed power and automaton state.

VI. Validation, Standards and Limits

Automatic validation checks finite signals, absence of collapse, UFLS triggering, return to restored state, state bounds and governor limits. The twelve checks executed over the two cases all pass.

The main limitations are the aggregated nature of the model, the absence of a detailed bus-line grid topology, and the use of calibrated demonstration parameters. An industrial study would require real protection settings, selectivity constraints, voltage-dependent load models and validated operator data.

Table III. Automatic project validation checks.

Case	Check	Result	Detail
ONEE	finite_signals	OK	All logged numeric signals must be finite.
ONEE	no_collapse	OK	Frequency nadir 48.956 Hz (collapse threshold 47.5 Hz).
ONEE	ufls_triggered	OK	Max shed 10.0 %.
ONEE	grid_restored	OK	Final shed 0.0 %, final state 0.
ONEE	state_bounds	OK	State range [0, 5].
ONEE	governor_bounds	OK	Pm_pu range [0.000, 0.150].
SENELEC	finite_signals	OK	All logged numeric signals must be finite.
SENELEC	no_collapse	OK	Frequency nadir 48.983 Hz (collapse threshold 47.0 Hz).
SENELEC	ufls_triggered	OK	Max shed 12.0 %.
SENELEC	grid_restored	OK	Final shed 0.0 %, final state 0.
SENELEC	state_bounds	OK	State range [0, 5].
SENELEC	governor_bounds	OK	Pm_pu range [0.000, 0.120].

VII. Conclusion

The simulation bench meets its objective: it demonstrates a complete chain from generation loss to frequency drop, Stateflow decision, load shedding and restoration. Automatic Simulink/Stateflow model generation supports graphical teaching, while the MATLAB scripts provide reproducible validation.

References

[1] P. Kundur, Power System Stability and Control, McGraw-Hill, 1994.

[2] IEEE Power System Relaying Committee, Underfrequency Load Shedding Protection, technical guidance.

[3] MathWorks, Simulink and Stateflow documentation, R2024a.

[4] Project scripts: main_simulation.m, build_stateflow.m, validate_project.m.