

Supplementary Material

Title: A Novel Fractional Order Controller for Stability Enhancement of Renewable Energy Integrated Multi Area Power System with Hybrid Energy Storage

Appendix A. Parameters of Test Systems

Power System:

$P_{R_1} = P_{R_2} = 2000$ MW (rating), $P_{L_1} = P_{L_2} = 1000$ MW (nominal loading), $f = 60$ Hz, $\beta_a = \beta_b = 0.425$ p.u. MW/Hz, $R_a = R_b = 2.4$ Hz/p.u. MW, $T_{gov_a} = T_{gov_b} = 0.03$ s, $T_{tur_a} = T_{tur_b} = 0.3$ s, $K_{gov_a} = K_{gov_b} = 1$ Hz/p.u. MW, $K_{tur_a} = K_{tur_b} = 1$ Hz/p.u. MW, $K_{ps_a} = K_{ps_b} = 120$ Hz/p.u. MW, $T_{ps_a} = T_{ps_b} = 20$ s, $T_{ab} = 0.545$ p.u MW/rad, $K_{ra} = K_{rb} = 0.333$ Hz/p.u. MW, $T_{ra} = T_{rb} = 10$ s, GDB = ± 0.036 , GRC = ± 0.0017

Boiler dynamic

$K_1 = 0.85$, $K_2 = 0.095$, $K_3 = 0.92$, $K_{IB} = 0.03$, $T_{IB} = 26$, $T_{RB} = 6.9$, $T_d = 0$, $T_f = 10$

PV System

Rating : 6 MW, $K_{pvs} = 1$ Hz/p.u. MW, $T_{pvs} = 1.8$ s

Wind turbine System

Rating: 5 MW, Diameter of Rotor: 126 m, Hub diameter : 3 m, Cut-in wind speed : 3 m/s, $\rho : 1.225$ Kg/m³, $\lambda_{tip} : 7.55$, $V_{wind} : 11.4$ m/s, $\omega_{rotor} : 12.1$ rpm, $R = 61.5$ m, $c_1 : 0.517$, $c_2 : 116$, $c_3 : 0.4$, $c_4 : 5$, $c_5 : 21$, $c_6 : 0.0068$, $\beta = 0$.

Energy storage System

BESS : $K_{(BESS)} = -\frac{1}{300}$, $T_{(BESS)} = 0.1$ s; FESS : $K_{(FESS)} = -\frac{1}{100}$; $T_{(BESS)} = 0.1$ s; UCES : $K_{(UCES)} = -\frac{7}{10}$, $T_{(BESS)} = 0.1$ s; SMES : $K_{(SMES)} = 0.205$, $T_{(SMES)} = 0.03$ s, $T_1 = 0.233$ s, $T_2 = 0.16$ s, $T_3 = 0.7087$ s, $T_4 = 0.2481$ s

Appendix B. Parameters of HCO

- population size : 50,
- selection probability weight $w = 0.7$,
- velocity influence coefficient $w_1 = 0.4$,
- acceleration coefficients (C_1 and C_2) = 1.5,
- λ is random number in the range [0, 1].