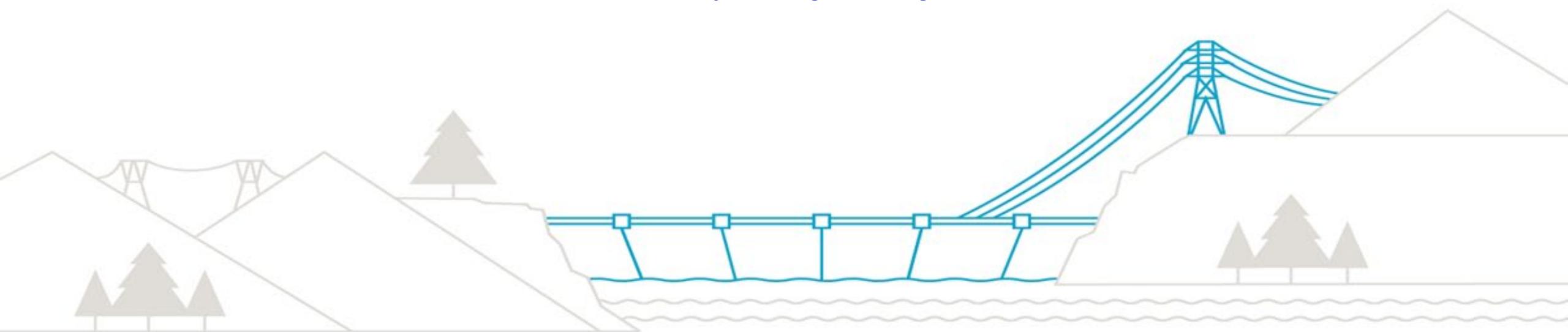


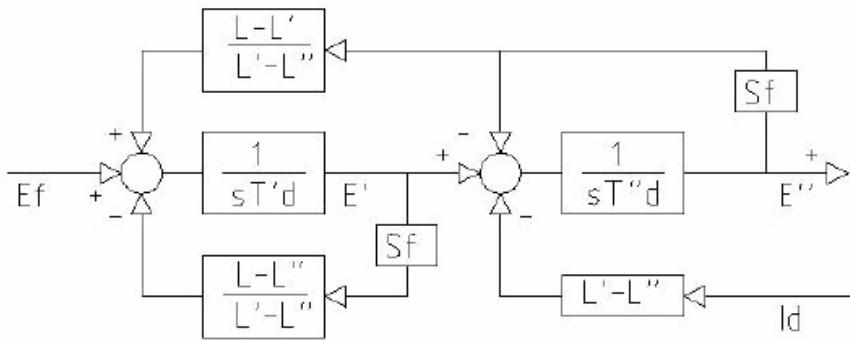
Understanding GENTPJ Model

Quincy Wang, P. Eng.



GENTPJ Model Specification

The detailed equations used in gentpf and gentpj are given by (1) through (20). With the parameter K_{is} set to zero in (1.19) the gentpj model is identical to gentpf. The saturation function appearing in (1.19) is the open circuit magnetization curve. Equations (1)-(20) correspond to the transfer function diagram shown below.



This diagram is indicative but, because of the nonlinear nature of (1)-(20), should not be used as a basis for implementing the model; implementation requires direct use of the full set of equations.

- Represented by a set of 20 equations
- Based on earlier GENTPF model
- No derivation process provided

$$V_q = E_{q1} + E_{q2} - I_q R_a - I_d X_{ds} \quad (1)$$

$$V_d = E_{d1} + E_{d2} - I_d R_a + I_q X_{qs} \quad (2)$$

$$E''_q = E_{q1} + E_{q2} - I_d X_{ddds} \quad (3)$$

$$E''_d = E_{d1} + E_{d2} + I_q X_{qqqs} \quad (4)$$

$$E'_q = E_{q1} + E_{q2} - ((X'_d - X''_d)/(X_d - X''_d)) E_{q2} - I_d X_{dds} \quad (5)$$

$$E'_d = E_{d1} + E_{d2} - ((X'_q - X''_q)/(X_q - X''_q)) E_{d2} + I_q X_{qqs} \quad (6)$$

$$dE''_q/dt = -(1 + S_d)((X'_d - X''_d)/(X_d - X''_d)) E_{q2}/T''_{do} \quad (7)$$

$$dE''_d/dt = -(1 + S_q)((X'_q - X''_q)/(X_q - X''_q)) E_{d2}/T''_{qo} \quad (8)$$

$$dE'_q/dt = (E_{fa} - (1 + S_d)E_{q1})/T'_{do} \quad (9)$$

$$dE'_d/dt = -(1 + S_q)E_{d1}/T'_{qo} \quad (10)$$

$$X_{ds} = ((X_d - X_l)/(1 + S_d)) + X_l \quad (11)$$

$$X_{dds} = (X_d - X'_d)/(1 + S_d) \quad (12)$$

$$X_{ddds} = (X_d - X''_d)/(1 + S_d) \quad (13)$$

$$X_{qs} = ((X_q - X_l)/(1 + S_q)) + X_l \quad (14)$$

$$X_{qqs} = (X_q - X'_q)/(1 + S_q) \quad (15)$$

$$X_{qqqs} = (X_q - X''_q)/(1 + S_q) \quad (16)$$

$$E_l = \sqrt{((V_q + I_q R_a + I_d X_l)^2 + (V_d + I_d R_a - I_q X_l)^2)} \quad (17)$$

$$I = \sqrt{I_d^2 + I_q^2} \quad (18)$$

$$S_d = (\text{saturation function})(E_l + K_{is}I) \quad (19)$$

$$S_q = (X_q/X_d)S_d \quad (20)$$

GENTPJ and GENTPF Background

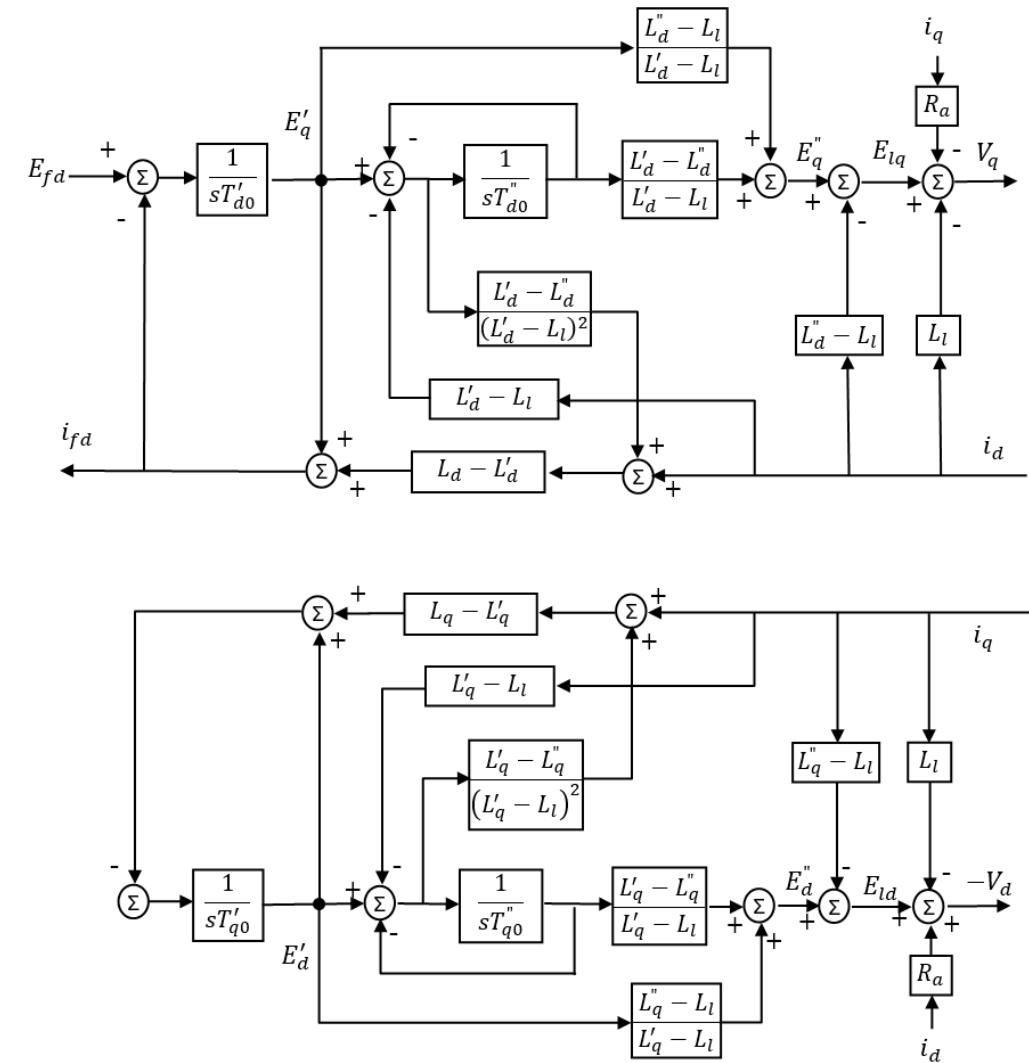
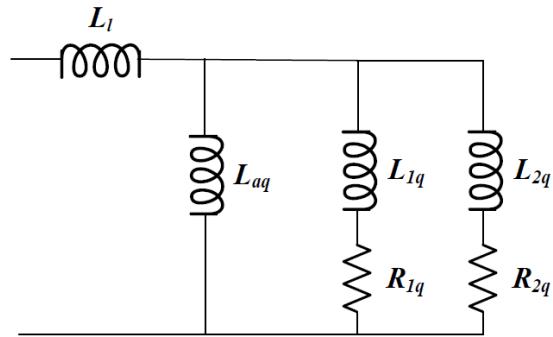
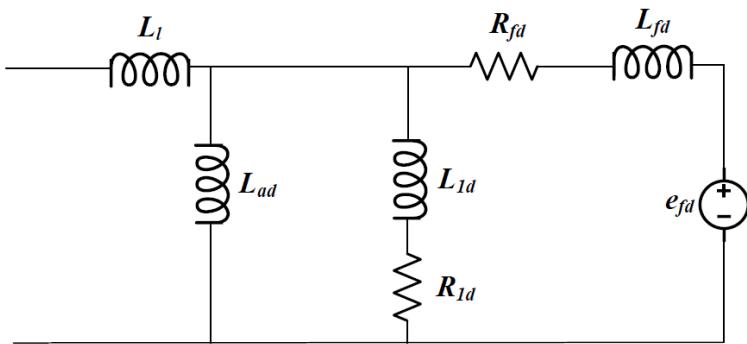
- Second-order generator models
- No detailed function block diagram expression available
- Do not truly represent the electromagnetic relations between the generator windings

Why, and What ?

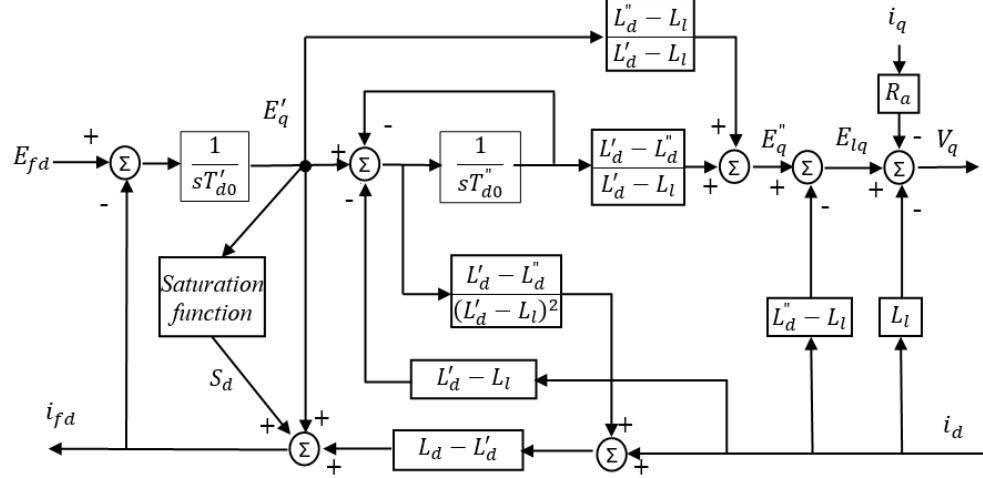
Synchronous Generator Models

- Simulated dynamic and steady-state performance with reasonable & acceptable level of accuracy
- Theoretical derivation to establish a foundation if possible
- Empirical results to guide the modeling theory improvement
- Verify and revise model through actual application practices

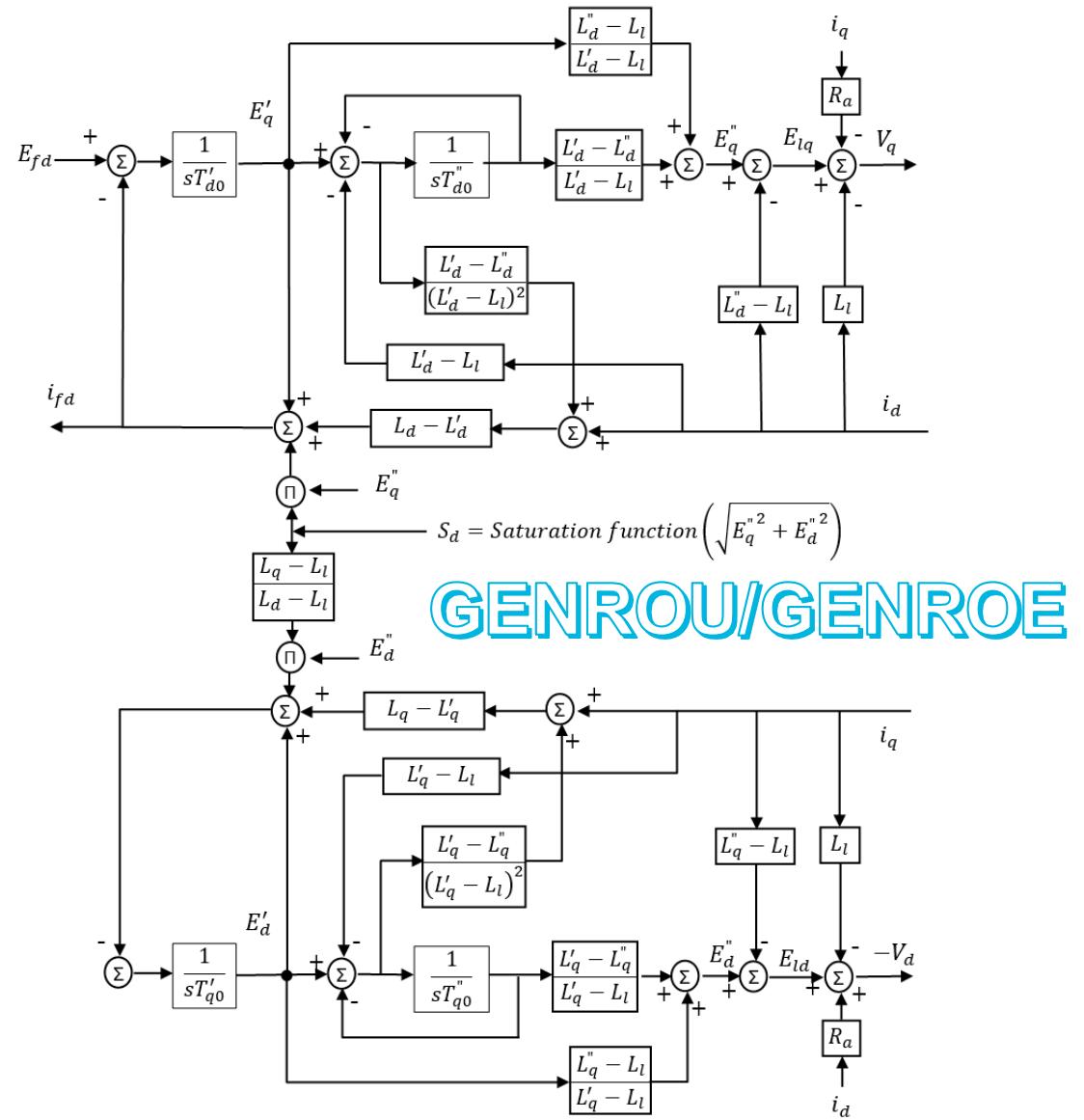
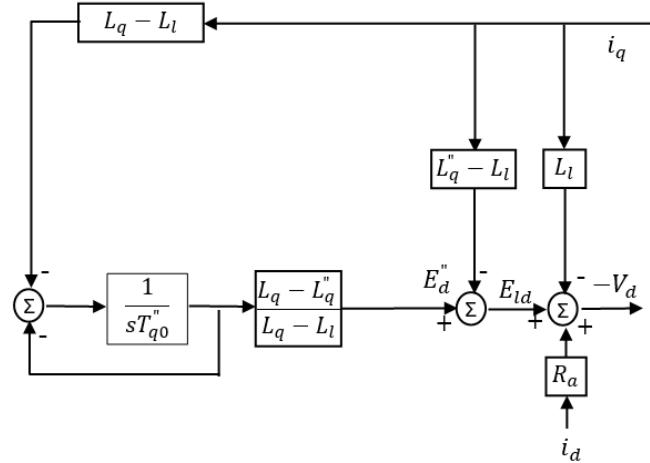
Second Order Generator Models



Conventional Models

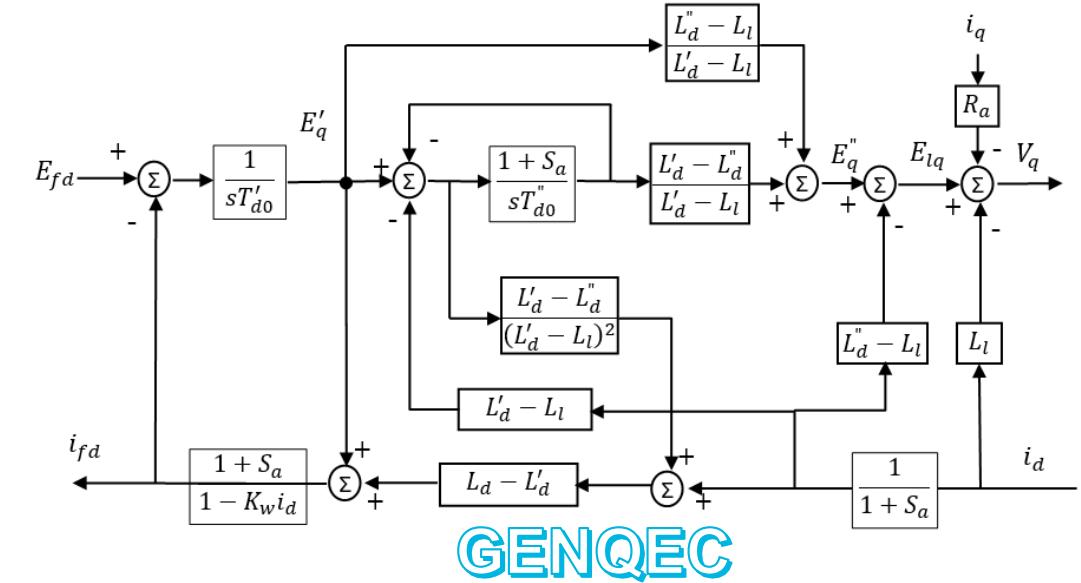
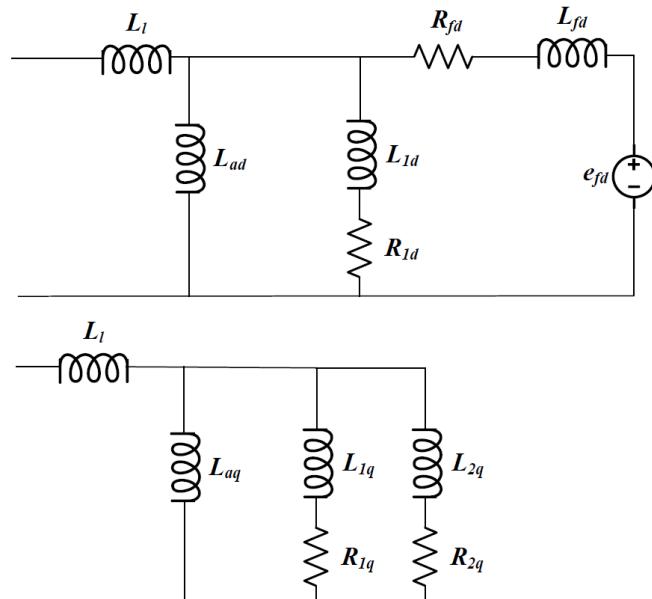


GENSAL/GENSAE

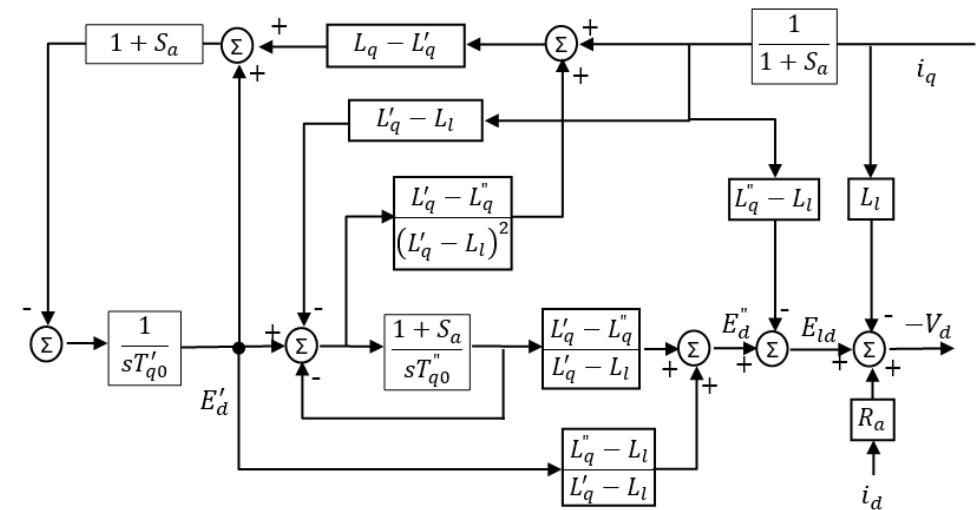


New Models

GENTPJ



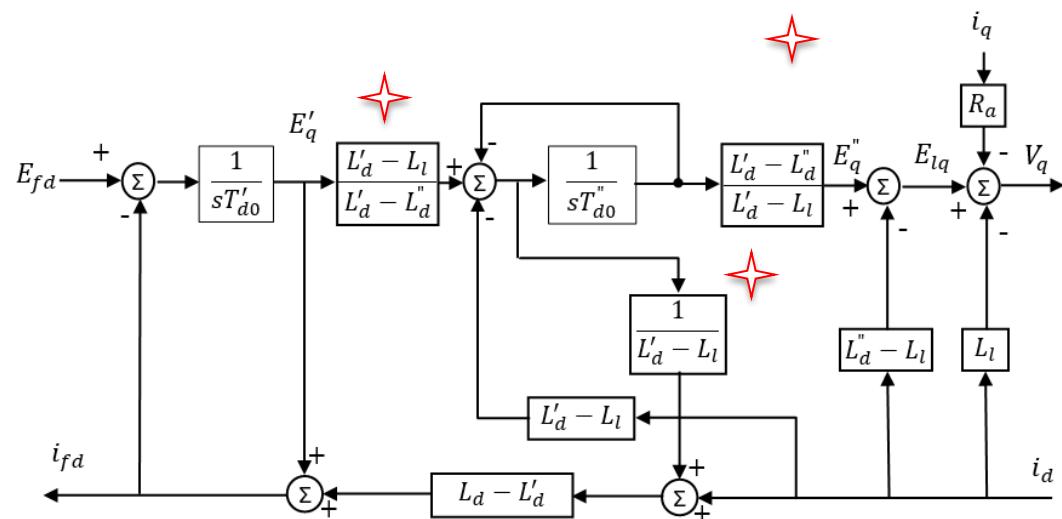
GENQEC



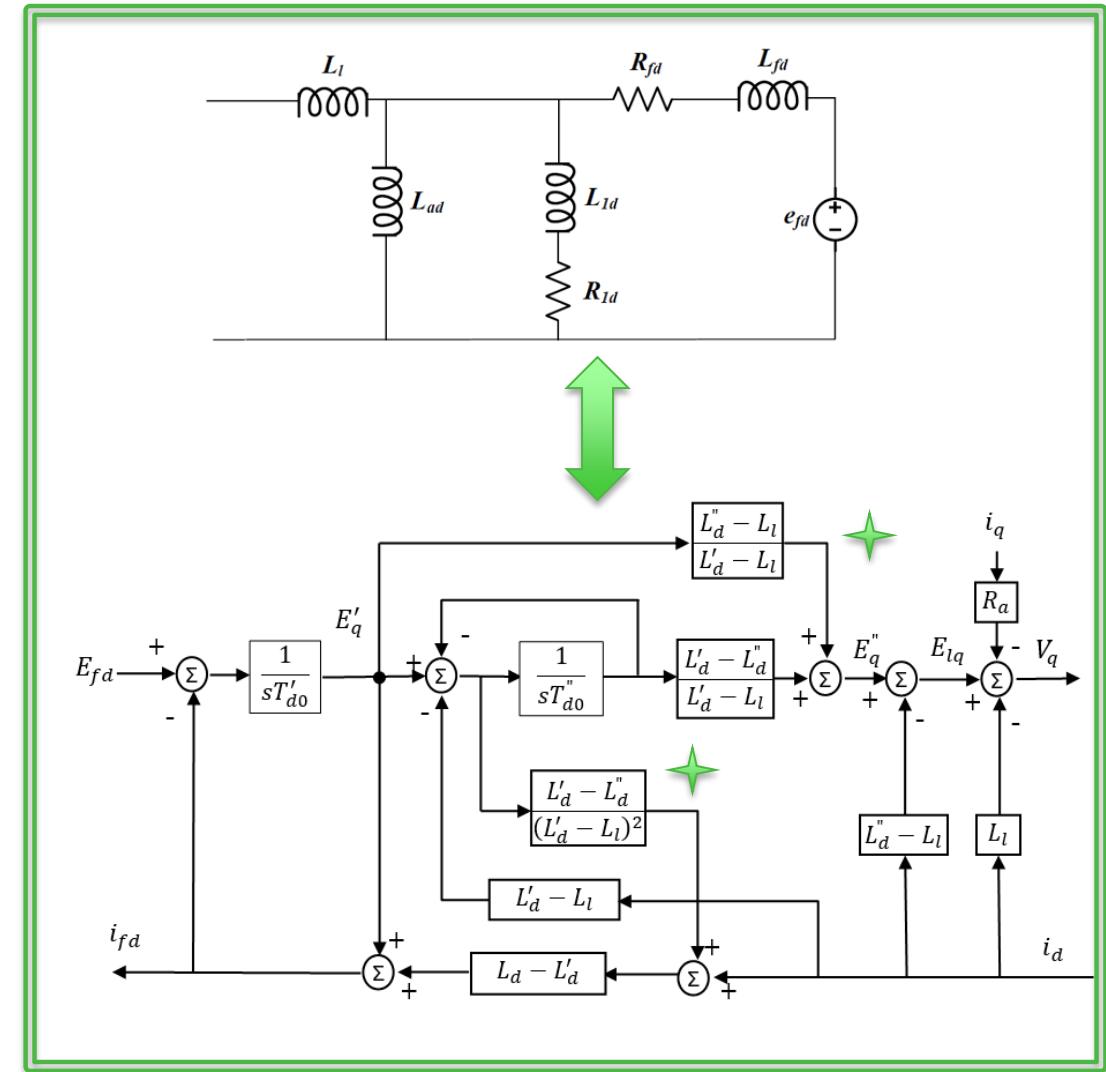
$$S_a = \text{Saturation function} \left(\sqrt{{E_{lq}}^2 + {E_{ld}}^2} \right)$$

GENTPJ simplification – D-axis linear

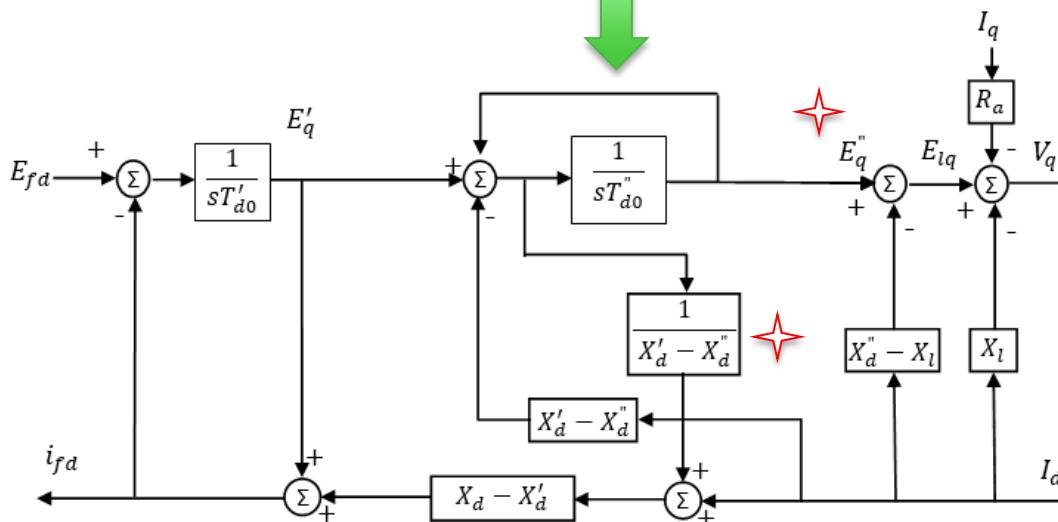
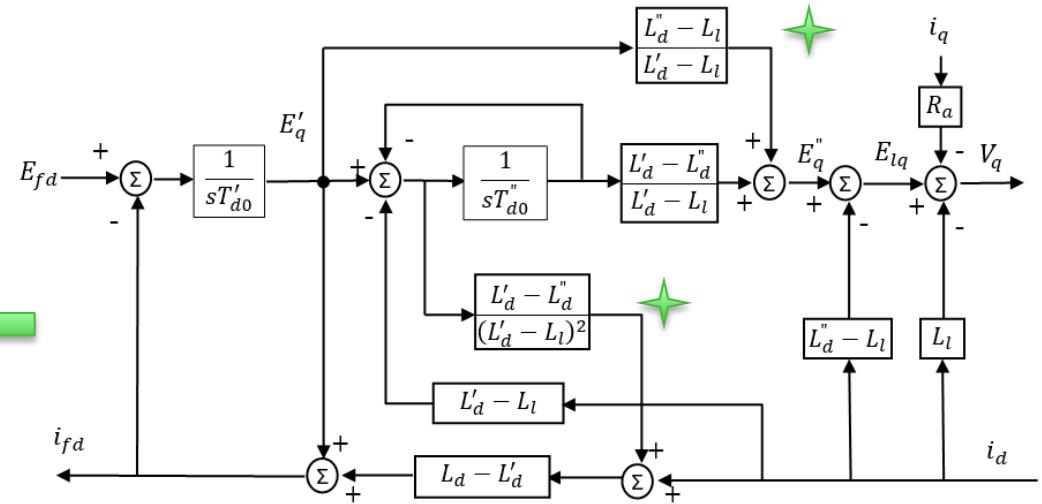
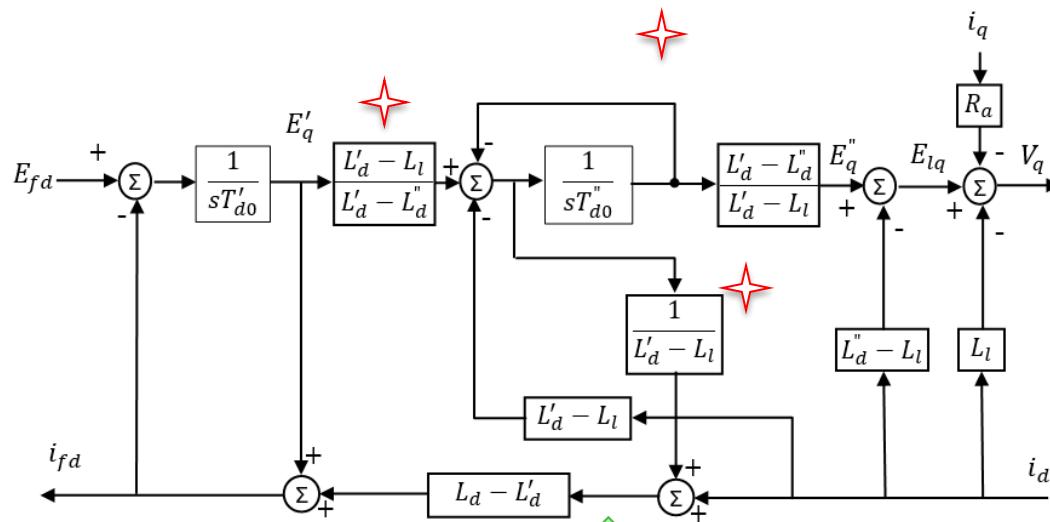
GENTPJ D-axis no-saturation



Proof of this block diagram in Appendix

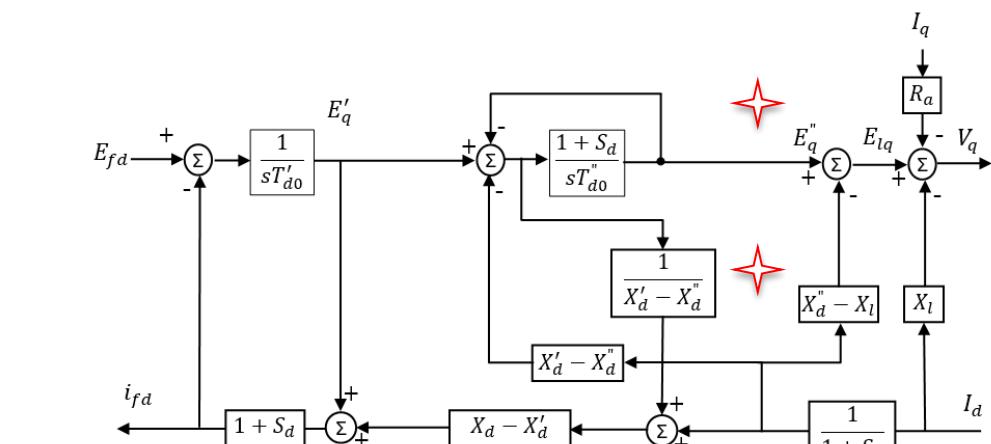


GENTPJ simplification – D-axis linear

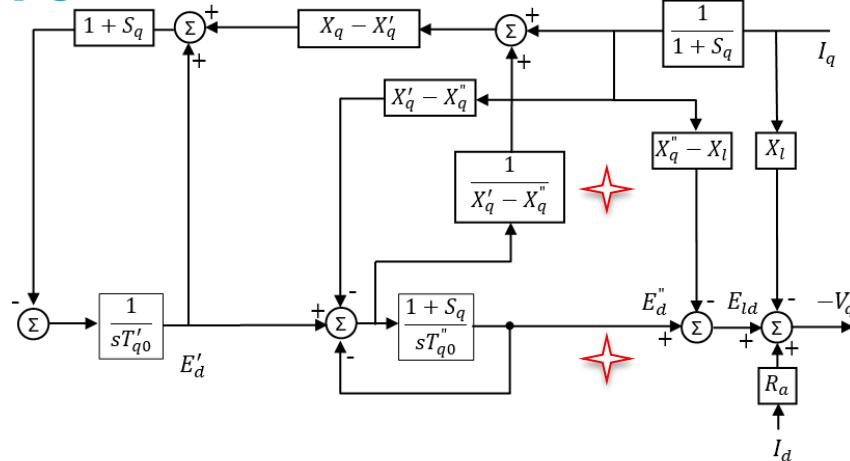


- Verified using GENTPJ equations with $Sd=0$
- Airgap fluxes only come from damper winding
- Stator armature reaction effect appears similar, may have difference

GENTPJ simplification



GENTPJ

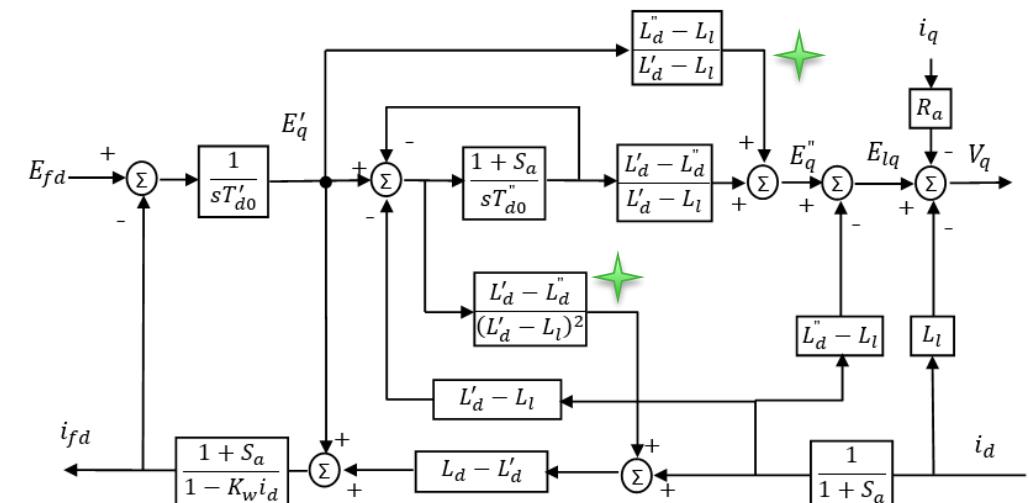


$$S_d = \text{Saturation function} \left(\sqrt{E_{lq}^2 + E_{ld}^2} + K_{ts} \sqrt{I_q^2 + I_d^2} \right)$$

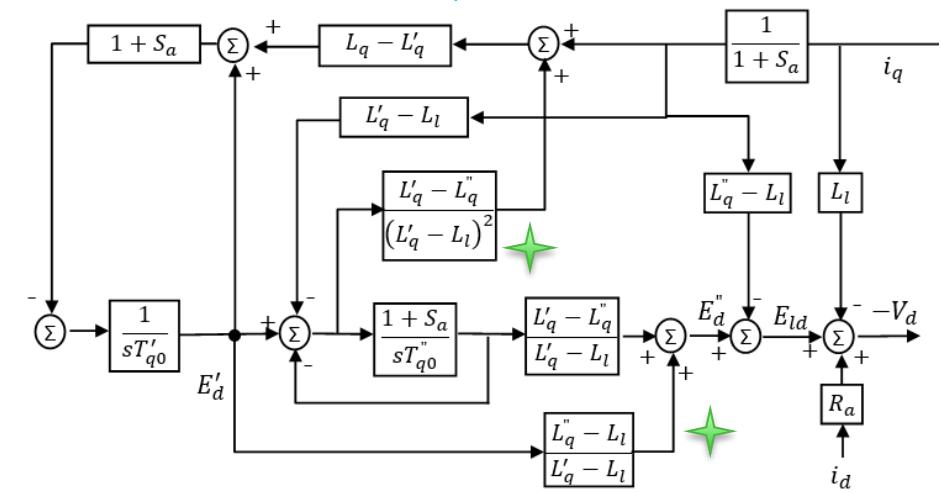
$$S_q = \frac{X_q}{X_d} S_d$$

10

Proof of this block diagram's d-axis in Appendix



GENQEC



$$S_a = \text{Saturation function} \left(\sqrt{E_{lq}^2 + E_{ld}^2} \right)$$

Transfer Function $sG(s)$

$$\Delta \psi_d(s) = G(s)\Delta e_{fd}(s) - L_d(s)\Delta i_d(s)$$

$$\Delta \psi_q(s) = -L_q(s)\Delta i_q(s)$$

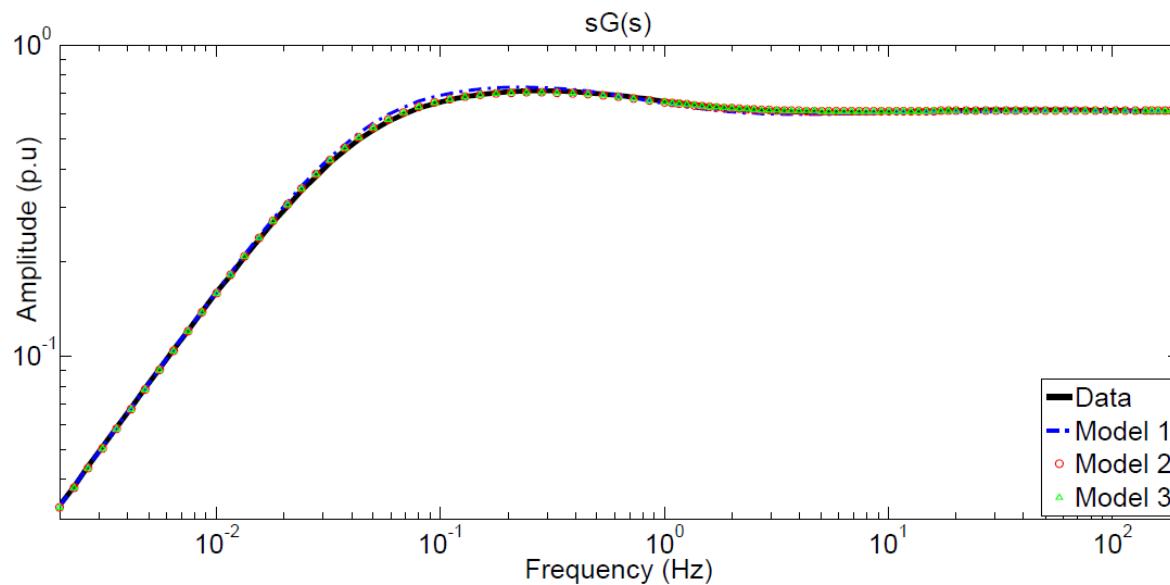
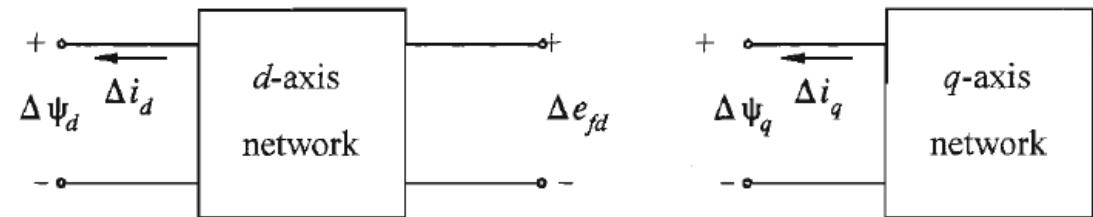


Figure H.3—Plots of magnitude of $sG(s)$ transfer function

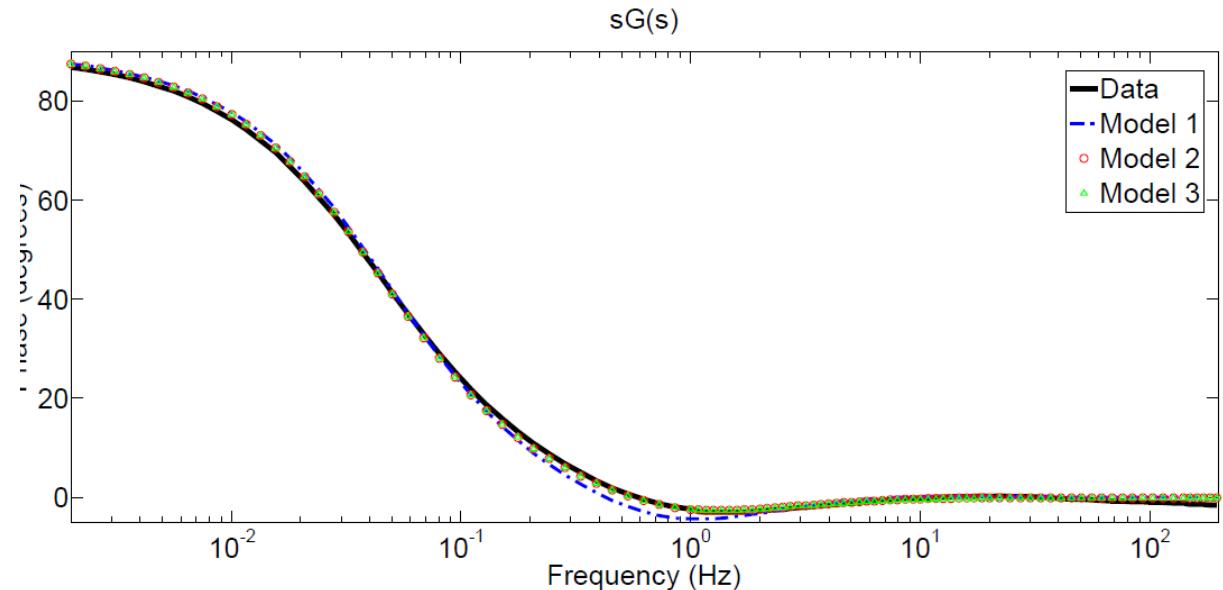
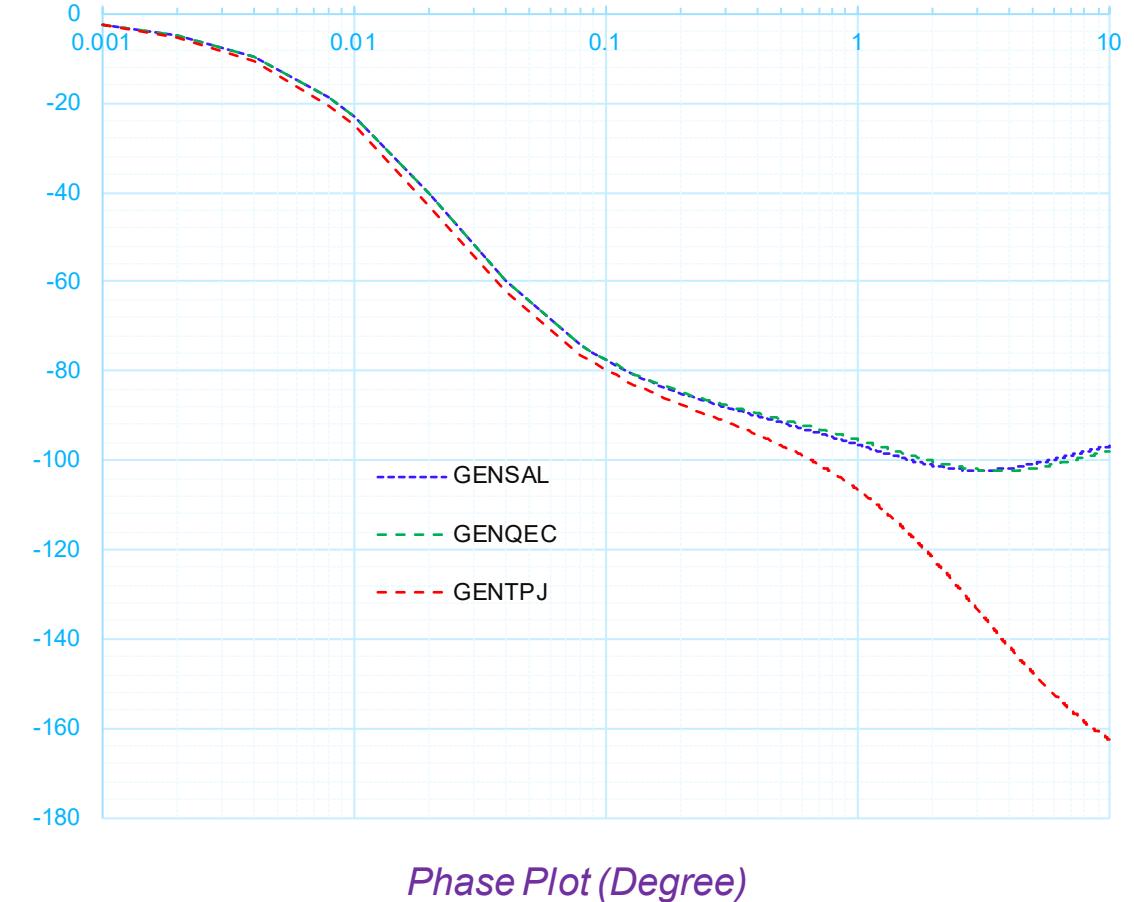
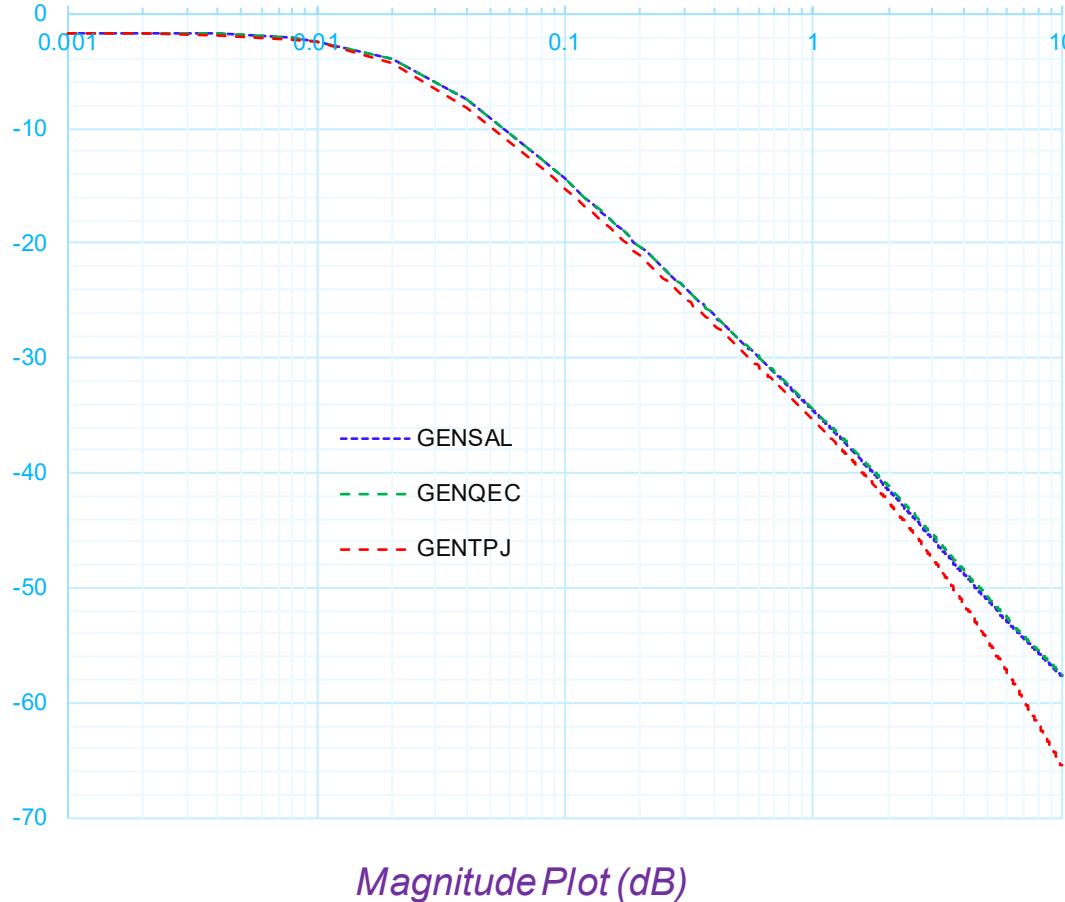


Figure H.4—Plots of phase angle of $sG(s)$ transfer function

Annex H, IEEE Std 115-2019

Impact of GENTPJ simplification, $G(s)$



Transfer Function $sG(s)$

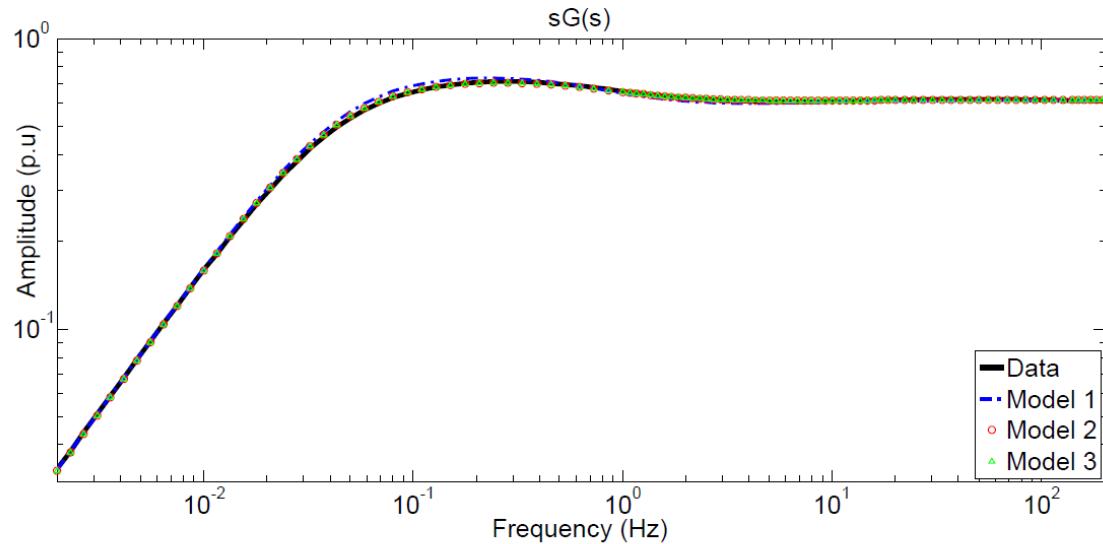


Figure H.3—Plots of magnitude of $sG(s)$ transfer function

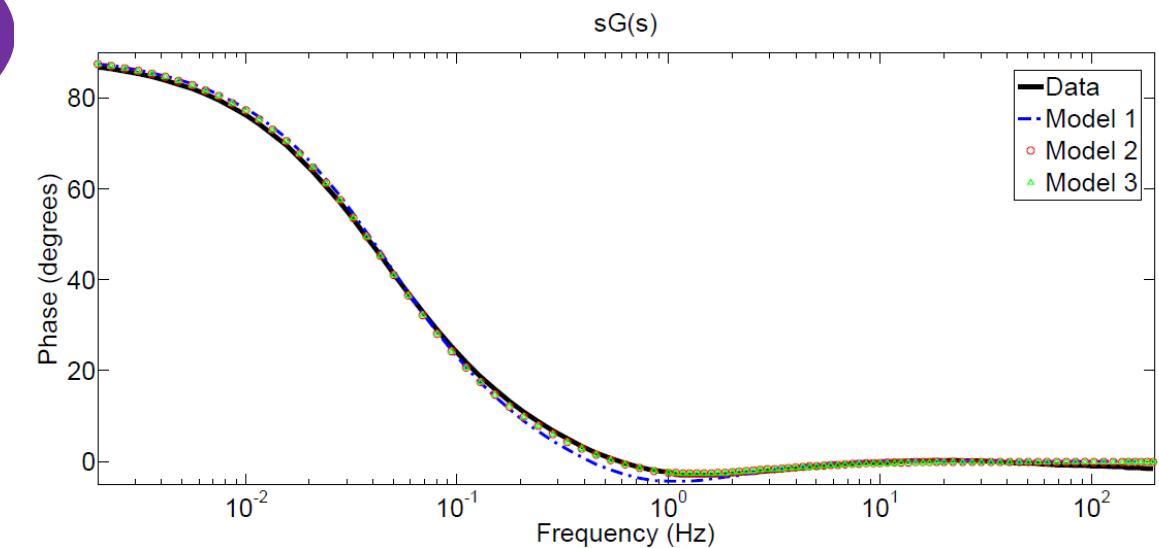
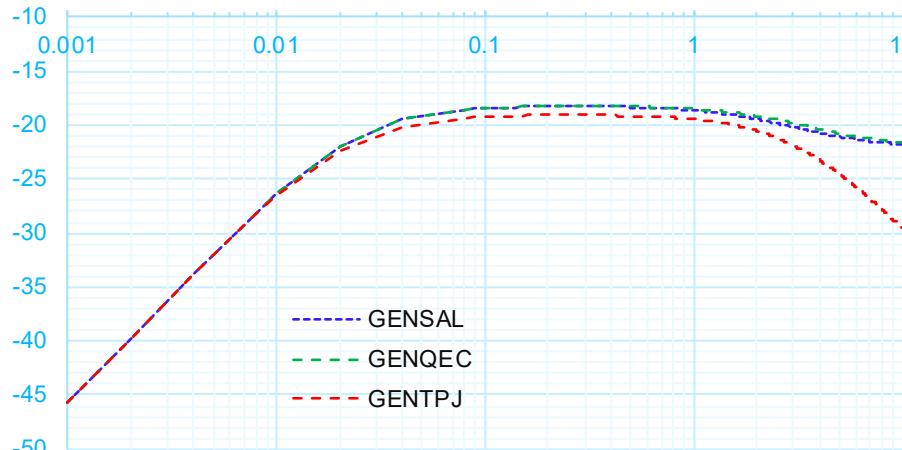
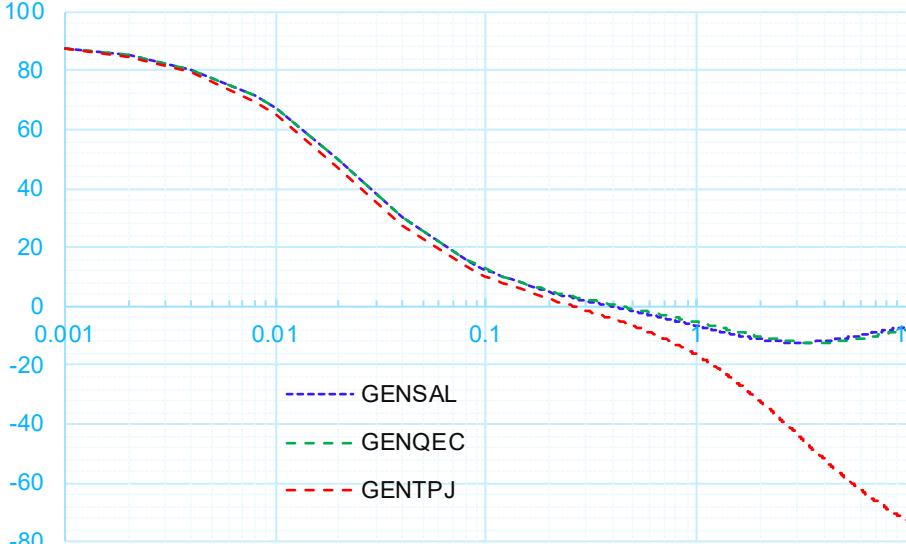
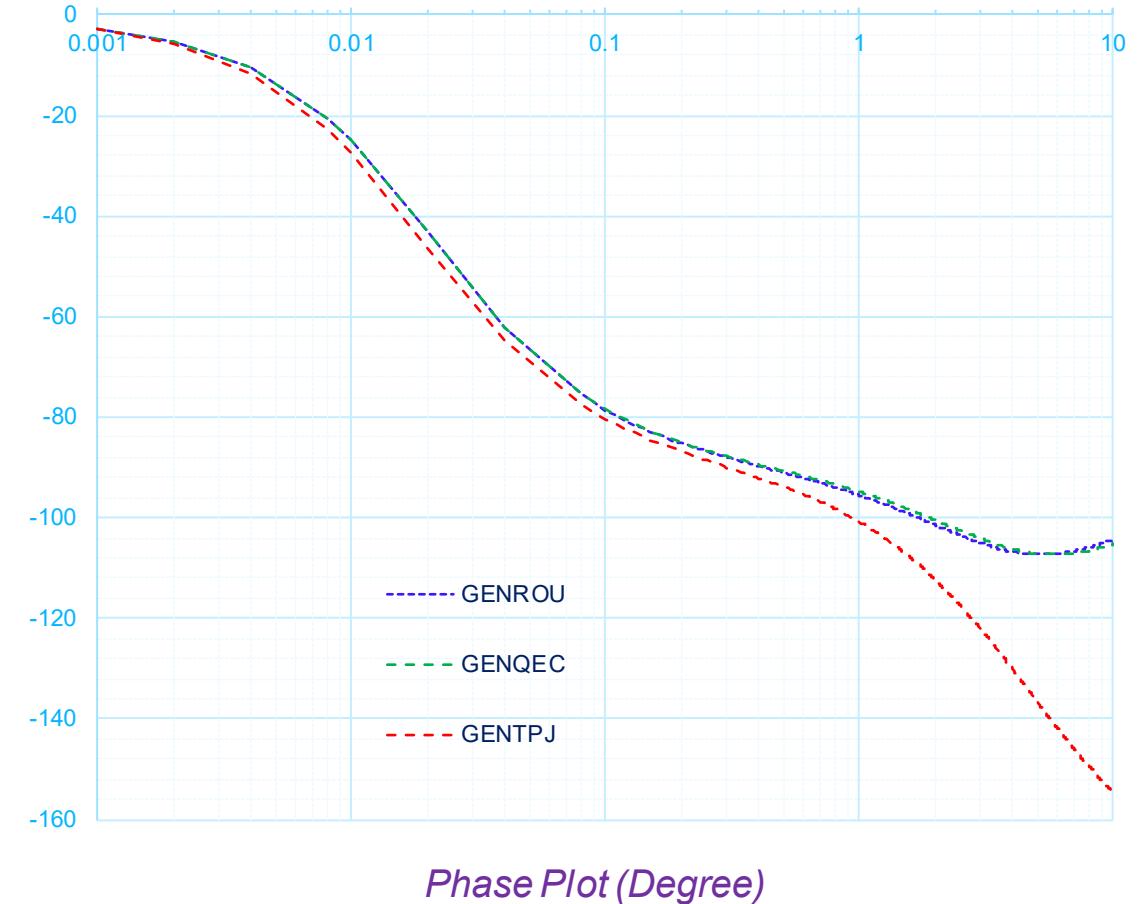
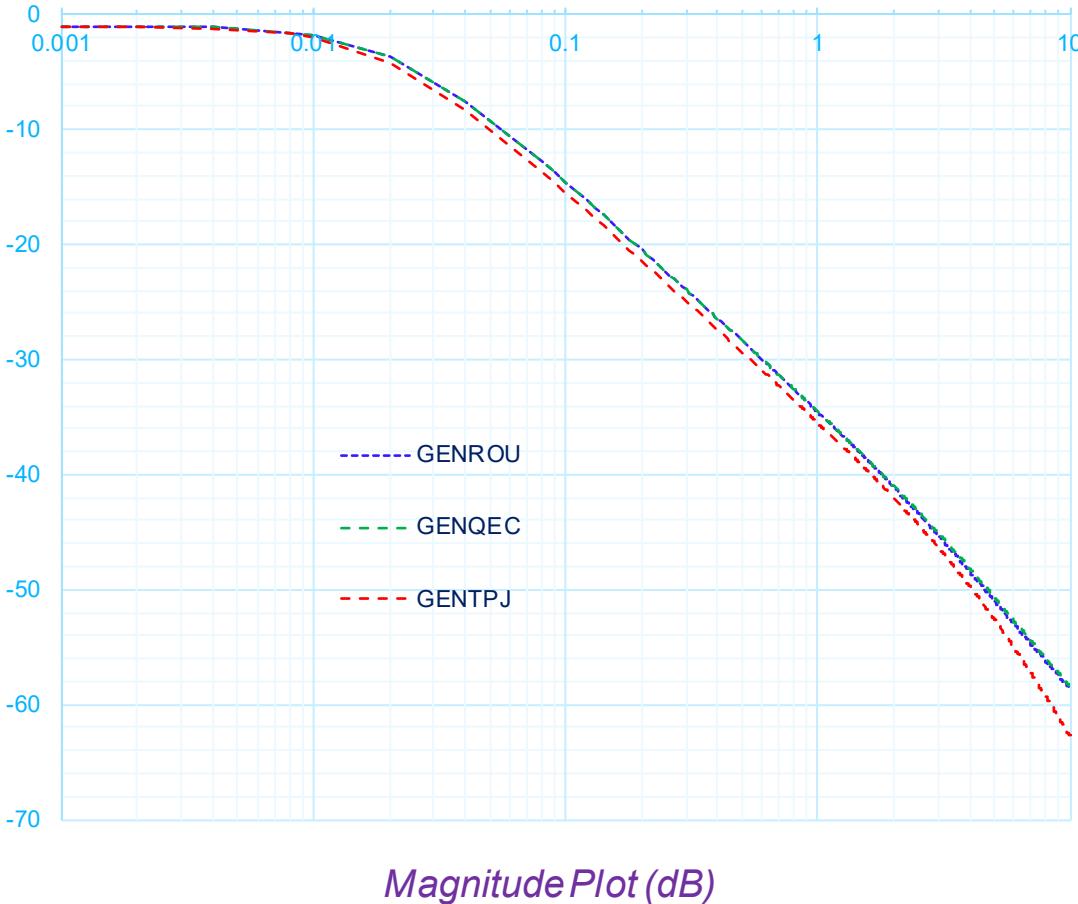


Figure H.4—Plots of phase angle of $sG(s)$ transfer function



Impact of GENTPJ simplification, $G(s)$



Transfer Function $sG(s)$

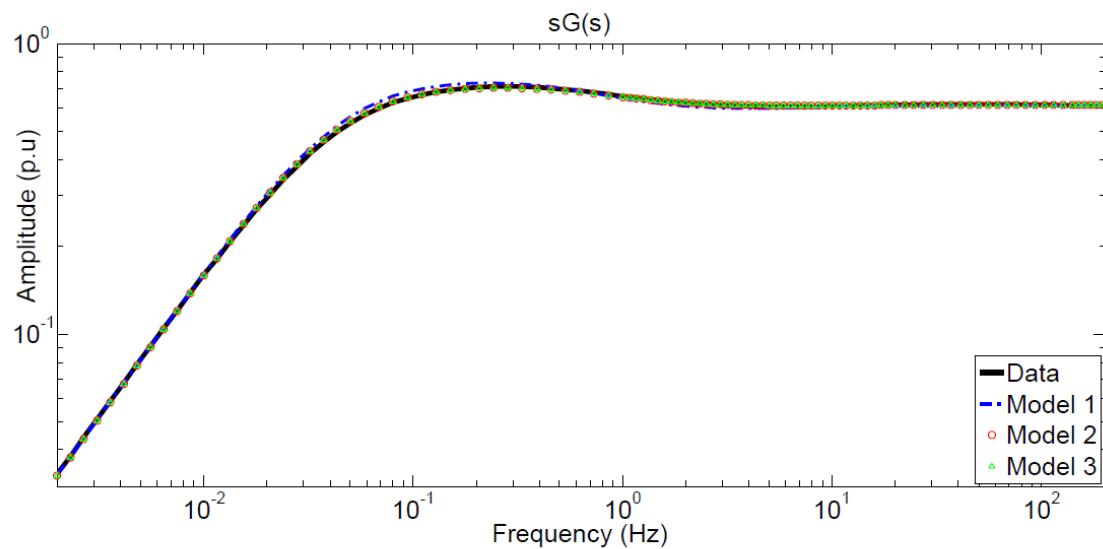


Figure H.3—Plots of magnitude of $sG(s)$ transfer function

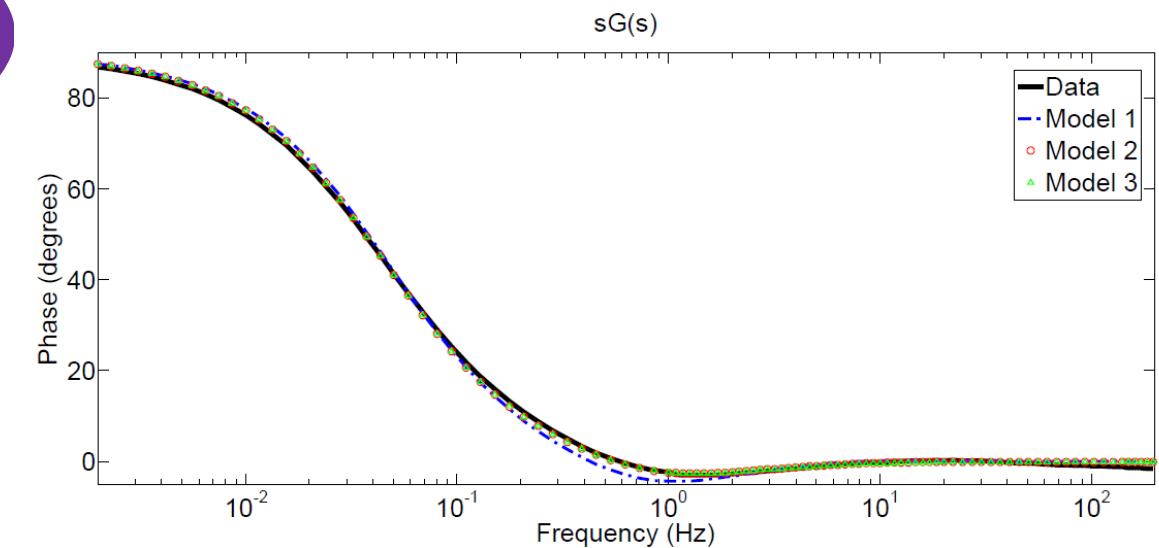
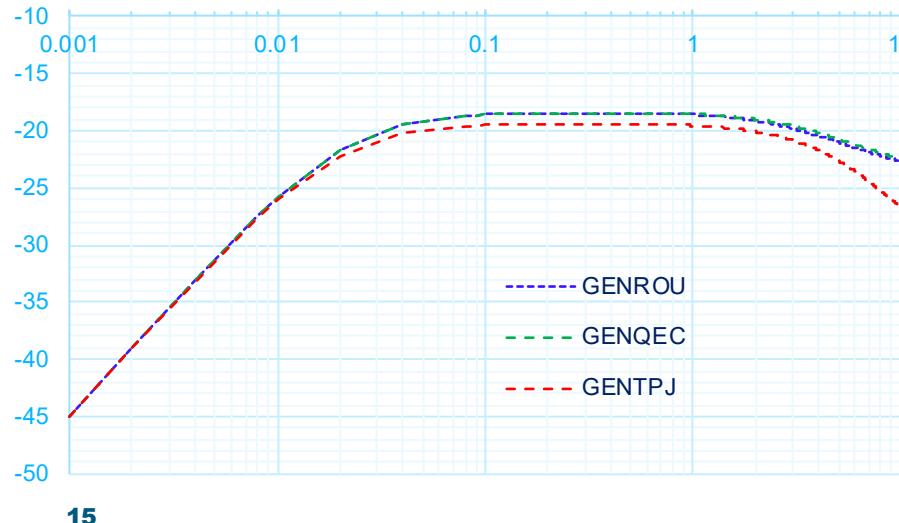
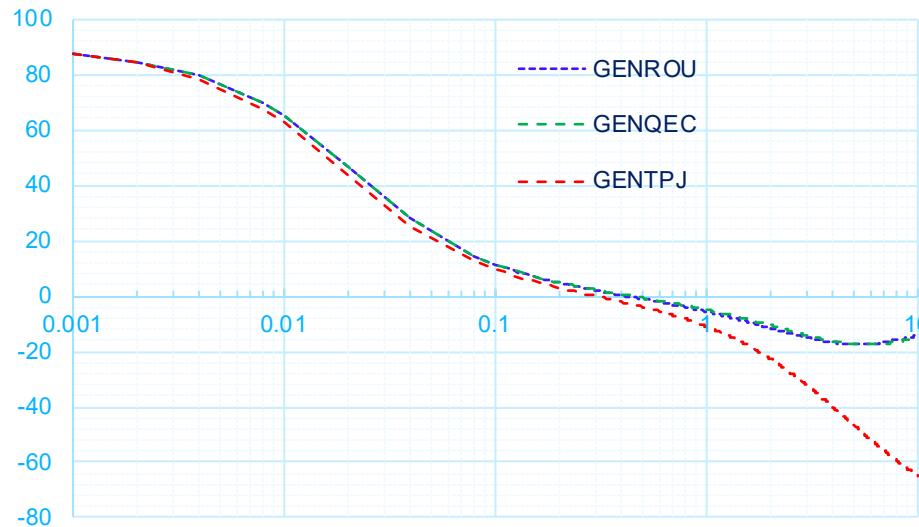


Figure H.4—Plots of phase angle of $sG(s)$ transfer function

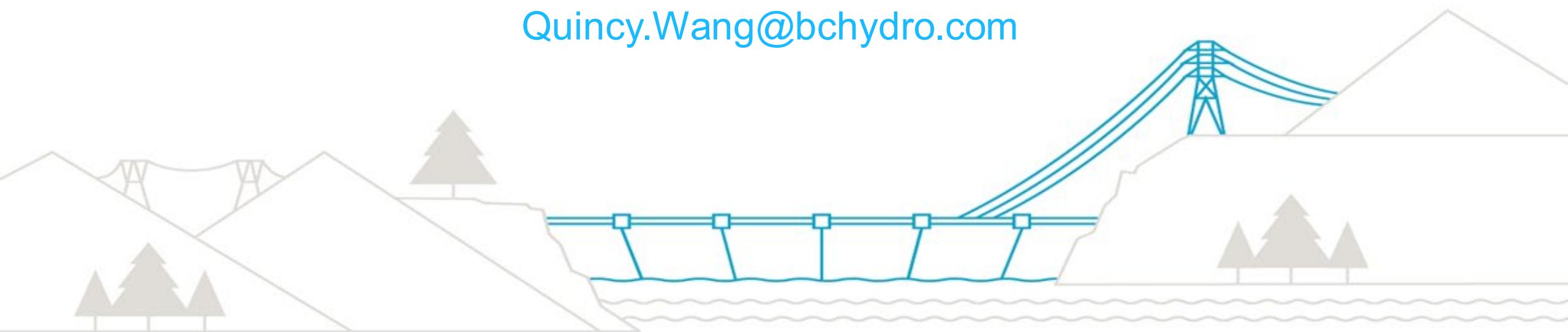


CONCLUSIONS

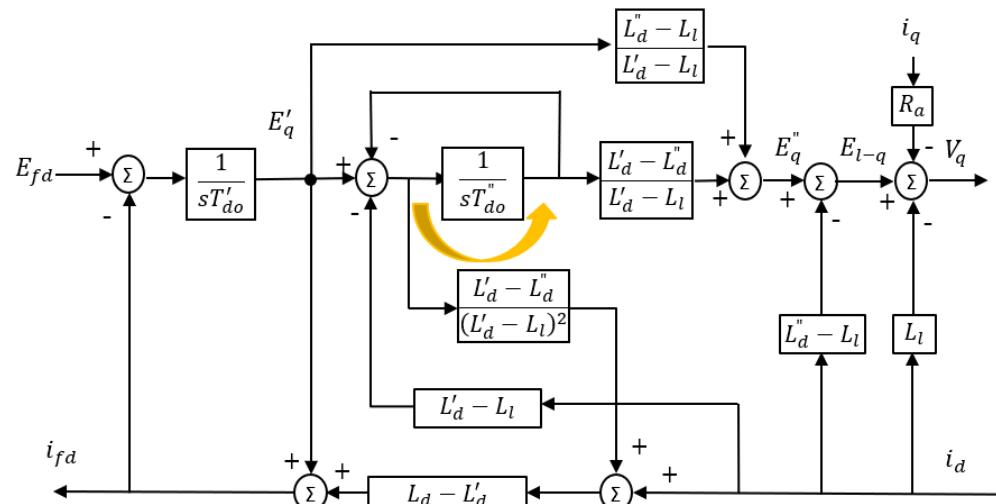
- In linear format, GENTPJ is modified from a common platform shared by some other 2nd-order generator models;
- The modifications in GENTPJ made it not truly representing the electromagnetic relations between generator stator and rotor windings;
- GENTPJ has inherent inaccuracy in representing generators dynamic performance;
- GENTPJ not suitable for standstill frequency response method described in IEEE Std-115;
- GENTPJ's impacts on generator parameter validation using other methods not fully known.

Thank You !

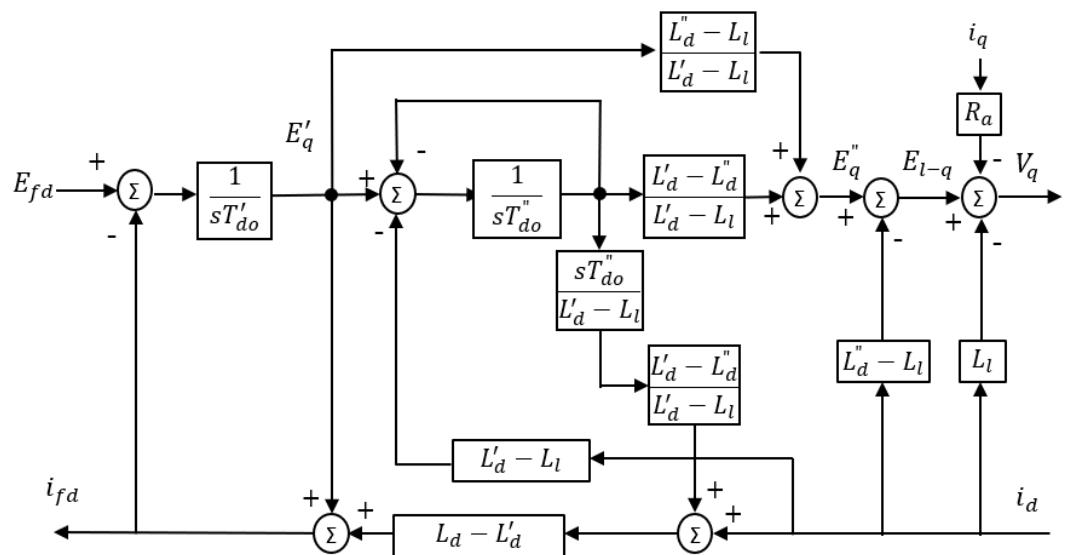
Quincy.Wang@bchydro.com



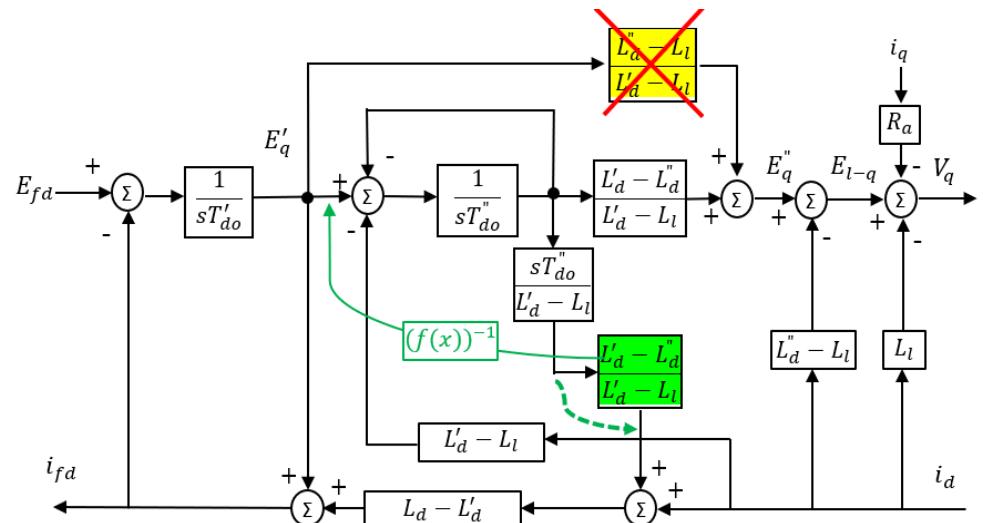
Appendix - GENTPJ Block Diagram



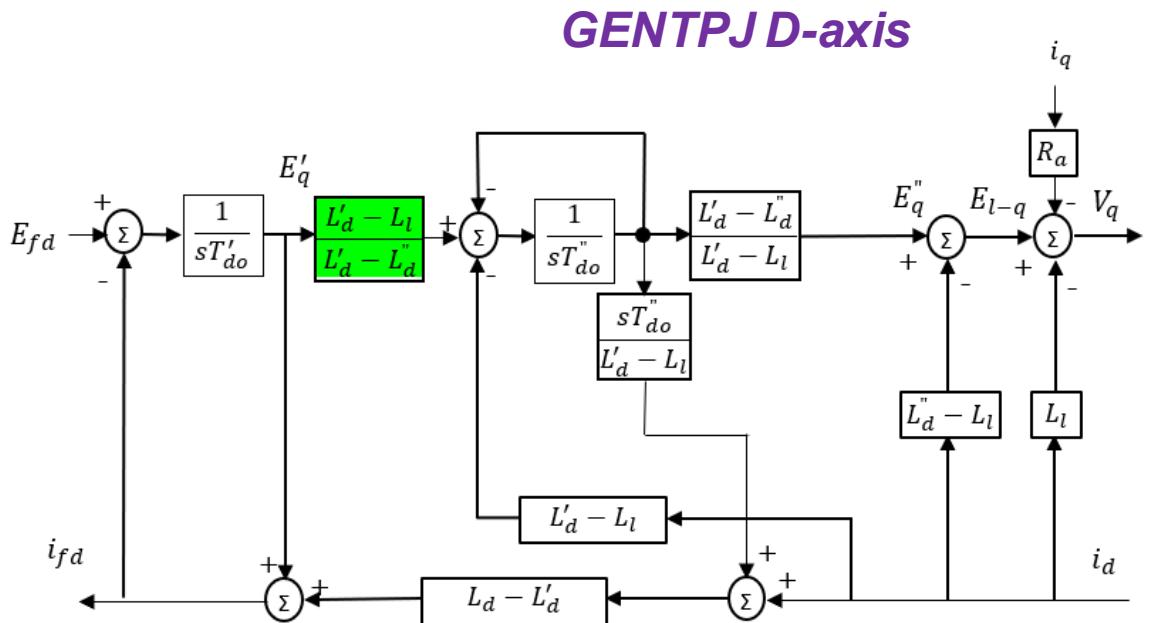
Generic d-axis block diagram



Appendix - GENTPJ Block Diagram

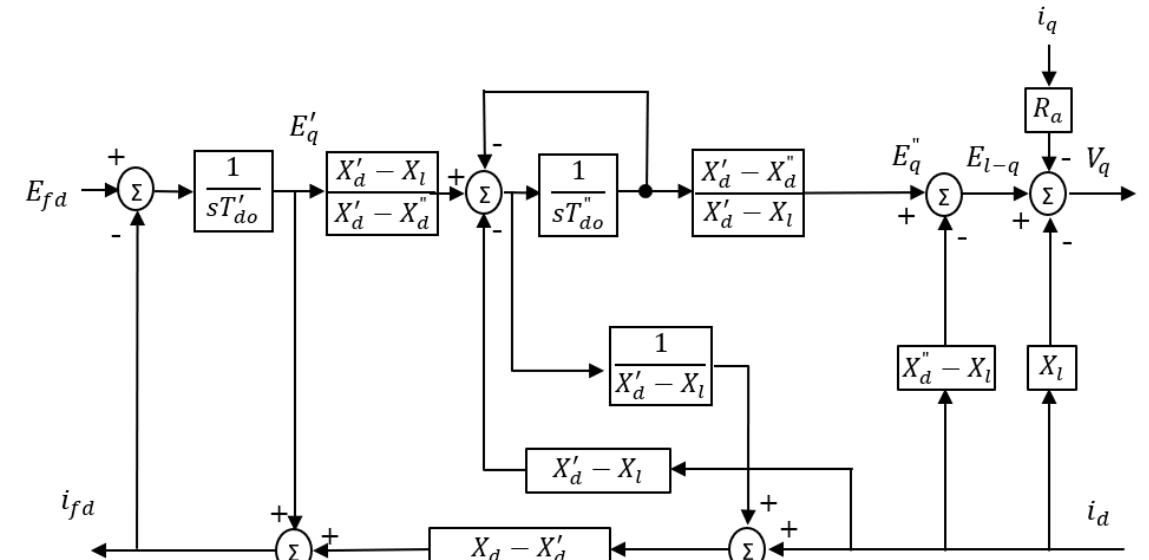
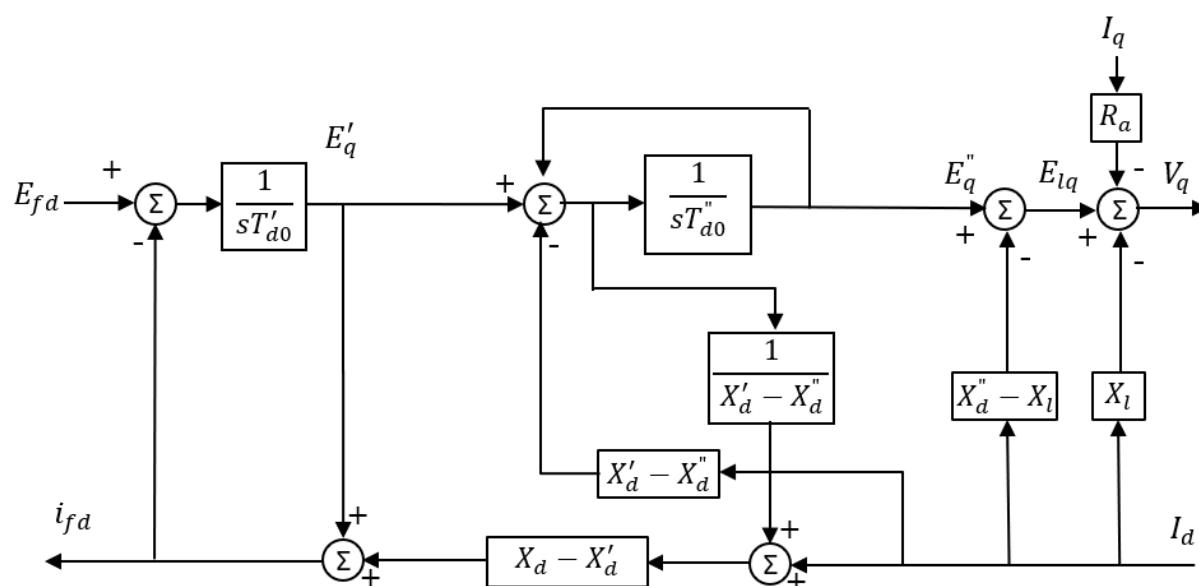


Changes made



GENTPJ D-axis

Appendix - GENTPJ Block Diagram



Appendix - GENTPJ D-axis

$Sd=0$. In GENTPJ Model specification equations.

From (7), $sT''doE''q = -(X'd - X''d)/(Xd - X''d)$ Eq2.

From (12), $Xdd_s = Xd - X'd$.

Substitute (Eq1+Eq2) from (3) and above into (5),

$$E'q = (1 + sT''do) E''q + Id (X'd - X''d)$$

From (5), $E'q = Eq1 + Eq2 * (Xd - X'd)/(Xd - X''d) - Id (Xd - X'd)$.

Substitute Eq2 using relation from (7),

$$Eq1 = E'q + (Xd - X'd)/(X'd - X''d) * sT''do E''q + Id (Xd - X'd)$$

Substitute into (9),

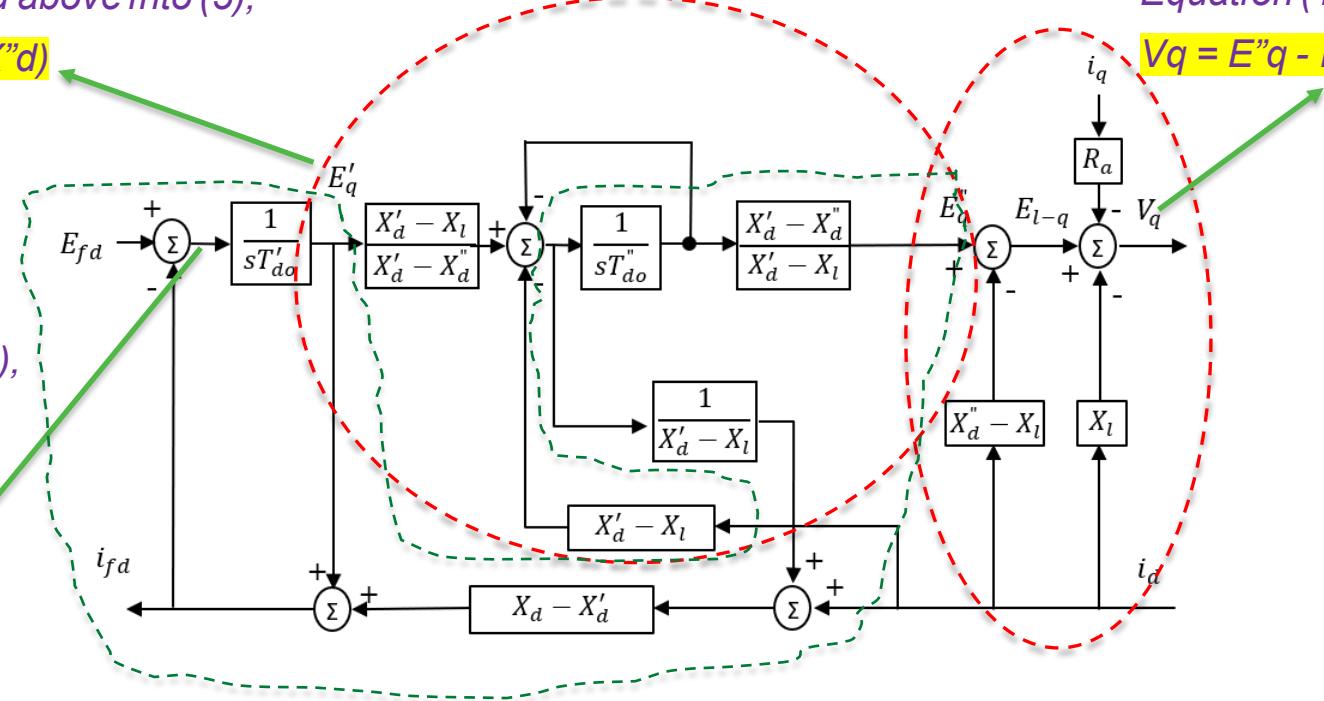
$$sT'do E'q = Efd - E'q - sT''do E''q * (Xd - X'd)/(X'd - X''d) - Id (Xd - X'd)$$

From (11), $Xds = Xd$;

from (13) $Xddds = Xd - X''d$.

Equation (1) subtract (3),

$$Vq = E''q - Iq * Ra - Id * X''d$$



Equations (1), (3), (5), (7), (9), (11), (12) and (13) for d-axis relations are all used and covered. Q-axis diagram is similar.

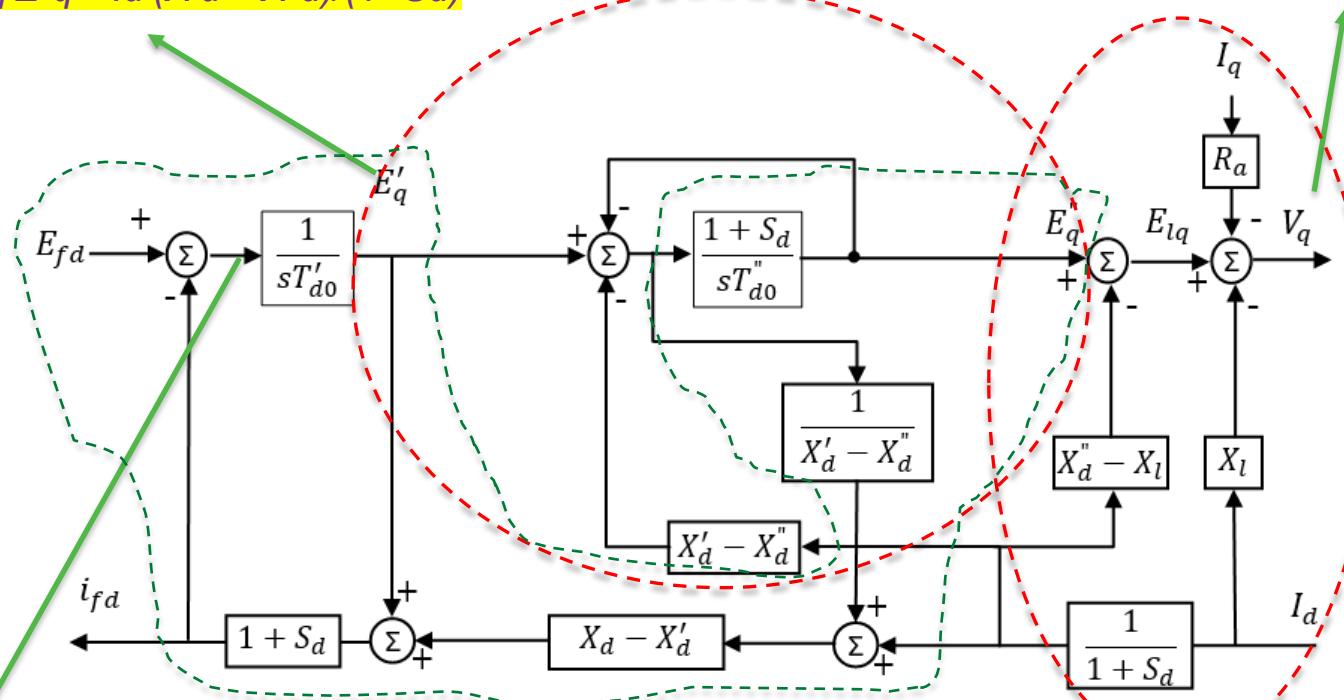
Appendix - GENTPJ D-axis

From (7), (12), (3) and (5),

$$E'q = [1 + sT''do / (1+Sd)] E''q + Id (X'd - X''d) / (1+Sd)$$

From (11), (13), (1) and (3):

$$Vq = E''q - Iq * Ra - Id (X''d - XI) / (1 + Sd) - Id * XI$$



From (7) & (5),

$$Eq1 = E'q + sT''do E''q (Xd - X'd) / (X'd - X''d) / (1+Sd) + Id (Xd - X'd) / (1+Sd)$$

Substitute into (9),

$$sT'do E'q = Efd - (1+Sd)[E'q + sT''do * E''q * (Xd - X'd) / (X'd - X''d) / (1+Sd) + Id (Xd - X'd) / (1+Sd)]$$

Equations (1), (3), (5), (7), (9), (11), (12) and (13) for d-axis relations are all used and covered. Q-axis diagram is similar.