## NOMENCLATURE

### (I) List of Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>$B_{ij}$</td>
<td>Imaginary part of $Z_{ij}$</td>
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<tr>
<td>$C_0$</td>
<td>State of charge of RFB</td>
</tr>
<tr>
<td>$C_2, C_3$</td>
<td>Domain characteristics of RFB</td>
</tr>
<tr>
<td>$D$</td>
<td>Damping Co-efficient (p.u. Kw/p.u.Hz)</td>
</tr>
<tr>
<td>$E_d'$</td>
<td>Generator Voltage behind transient reactance (p.u.)</td>
</tr>
<tr>
<td>$E_d''$</td>
<td>Generator Voltage behind subtransient reactance $X_d''$ (p.u.)</td>
</tr>
<tr>
<td>$E_d$</td>
<td>SMES Coil voltage (volts)</td>
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<tr>
<td>$E_{fd}$</td>
<td>Synchronous generator field voltage</td>
</tr>
<tr>
<td>$E_{do}$</td>
<td>Maximum output voltage of 6-pulse converter (volts)</td>
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<tr>
<td>$E_{eq}$</td>
<td>Generator voltage behind subtransient reactance $X_q''$ (p.u.)</td>
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<tr>
<td>$f$</td>
<td>System frequency (Hz)</td>
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<tr>
<td>$G_{ij}$</td>
<td>Real part of $Z_{ij}$</td>
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<tr>
<td>$H_A$</td>
<td>Total wind turbine and wind generator inertia constant (sec)</td>
</tr>
<tr>
<td>$H_b$</td>
<td>Width of current band of hysterises current controller</td>
</tr>
<tr>
<td>$H_D$</td>
<td>Inertia constant of synchronous machine coupled to diesel engine (sec)</td>
</tr>
<tr>
<td>$[I]$</td>
<td>Identity matrix</td>
</tr>
<tr>
<td>$i_0$</td>
<td>Self discharge current of RFB</td>
</tr>
<tr>
<td>$I_{sm}$</td>
<td>SMES coil current (Amp)</td>
</tr>
<tr>
<td>$I_{Dsm}$</td>
<td>Direct axis component of SMES current injected at the AC bus</td>
</tr>
<tr>
<td>$I_{Qsm}$</td>
<td>Quadrature axis component of SMES current injected at the AC bus</td>
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<tr>
<td>$I_d, I_q$</td>
<td>Direct and quadrature axis components of synchronous machine injected current $I_t$ (p.u.)</td>
</tr>
<tr>
<td>$I_D, I_Q$</td>
<td>Direct and quadrature axis components of induction machine injected current $I_t$ (p.u.)</td>
</tr>
<tr>
<td>$I_{DRFB}, I_{QRFB}$</td>
<td>Direct and Quadrature components of redox flow battery current (p.u.)</td>
</tr>
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</table>
\(I_d\): Nominal value of SMES coil current (Amp)
\(I_{dc}\): DC current through SMES
\(I_{ES}\): Energy storage injected current into network (p.u.)
\(i_a, i_B\): Current components in stationary reference frame
\(j\): imaginary axis operator
\(K_A\): Gain constant of AVR Amplifier
\(K_D\): Proportionality constant relating torque of diesel engine with diesel fuel consumption rate
\(K_E\): Gain constant of AVR exciter
\(K_R\): Gain constant of AVR input filter
\(L\): SMES coil inductance
\(L_f\): Coupling reactor inductance (mh)
\(L_T\): Inductance per unit length of transmission line
\(m_B\): Diesel fuel consumption rate (kg/sec)
\(P_{bat}\): Active power supplied by Redox flow battery
\(P_c\): Diesel governor integral controller output
\(P_{dem}\): Active power demanded from energy storage unit
\(P_E\): Active power supplied by energy storage unit
\(P_L\): Active power component of load
\(P_r\): Real power supplied by SMES unit
\(Q_{bat}\): Reactive power supplied by RFB
\(Q_{dem}\): Reactive power demanded by energy storage unit
\(Q_E\): Reactive power supplied by energy storage unit
\(Q_r\): Reactive power supplied by SMES unit
\(R\): Speed regulation (%)
\(R_1\): Contact resistance of RFB
\(R_2, R_3\): Domain characteristics of RFB
\(R_f\): Coupling reactor resistance (\(\Omega\))
\(R_L\): Resistance per unit length of transmission line
\(r_r\): Induction machine rotor resistance
\(r_s\): Induction machine stator resistance
S : Induction machine slip
s : Laplace operator
Sa, Sb, Sc : Switching functions (1 or 0) of VSC
TA : Time constant of AVR Amplifier
T_Ae : Electromagnetic torque developed by induction generator (p.u.)
T_Am : Mechanical torque developed by synchronous machine (p.u.)
T_De : Electromagnetic torque developed by synchronous machine (p.u.)
T_Dm : Torque developed by diesel engine (p.u.)
T_d0, T_d0* : Synchronous generator open circuit transient and subtransient time
  constants of direct axis (sec)
T_E : Time constant of AVR Exciter (sec)
T_F : Time constant of AVR stabilizer (sec)
T_0* : Induction machine rotor time constant (sec)
T_qo* : Synchronous generator open circuit subtransient time constant of
  quadrature axis (sec)
T_R : Time constant of AVR input filter (sec)
T_w : Wash-out time constant (sec)
V_D : Real component of machine terminal voltage (p.u.)
V_d : Direct axis component of machine terminal voltage (p.u.)
V_F : Output of AVR stabilizer
V_Q : Imaginary component of machine terminal voltage (p.u.)
V_q : Quadrature axis component of machine terminal voltage (p.u.)
V_R : Output of AVR input filter
V_ref : Reference voltage for AVR
|V_d| : Magnitude of machine terminal voltage (p.u.)
V_α, V_β : Voltage components in stationary reference frame
X : Induction machine open circuit reactance (p.u.)
X_c : Reactance of capacitor banks (p.u.)
X_d, X_q : Synchronous generator reactance of direct and quadrature axis (p.u.)
X_d*, X_q* : Synchronous generator transient reactance of direct and quadrature axis
  (p.u.)
\(X_d^*, X_q^*\) : Synchronous generator subtransient reactance of direct and quadrature axis (p.u.)

\(X_{Ls}\) : Commutation Reactance, \(2\pi f L_s\)

\(x_m\) : Reactance of magnetizing branch of induction machine

\(x_r\) : Induction machine rotor reactance (p.u.)

\(x_s\) : Induction machine stator reactance (p.u.)

\([Y_{\text{bus}}]\) : Bus admittance matrix

\([Y_{\text{TT}}]\) : Matrix of driving point and transfer admittances

\([Y_{\text{TT}}']\) : Admittances matrix, obtained after elimination of all the buses, excepting generator energy storage and load buses.

\([Z_{\text{TT}}]\) : Matrix of driving point and transfer impedances

\(\tau\) : Governor time constant (sec)

\(\omega_A\) : Wind generator angular velocity (p.u.)

\(\omega_0\) : Nominal frequency (\(2\pi f\), elect rad/sec)

\(\delta\) : Electrical angle of synchronous generator (rad)

\(\alpha\) : Firing angle of converters in equal \(\alpha\) mode

\(\alpha_1, \alpha_2\) : Firing angles of converters in unequal \(\alpha\) mode

\(\Delta\) : Incremental change of the associated variable (prefix)

\(\Delta \omega_D\) : Speed deviation of diesel unit (p.u.)

\(\mu\) : Membership function value
(II) Abbreviations

AC Alternating current
AVR Automatic voltage regulator
CBS Compensating capacitor banks
CC VSI Current Controlled Voltage Source Inverter
DC Direct current
EDLC Electric double layer capacitor
FAM Fuzzy associative memory
GF Governor Free
GTO Gate Turn Off
IEEE The Institute of Electric and Electronics Engineers Inc
ISTEC International Superconductivity Technology Center
IGBT Insulated gate bipolar transistor
LFC Load Frequency control
LN Large negative
LP Large positive
MN Medium negative
MP Medium positive
P Proportional
PCS Power Conversion System
Pf Power factor
p.u. Per unit
PI Proportional integral
PID Proportional integral derivative
PWM Pulse width modulation
RFB Redox flow battery
SEI Sumitomo Electric Industries
SMES Superconducting magnetic energy storage
SN Small negative
SOC State of charge
SP Small positive

xx
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>SUP_MIN</td>
<td>Supremum-Minimum</td>
</tr>
<tr>
<td>SVC</td>
<td>Static var compensator</td>
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<tr>
<td>TCR</td>
<td>Thyristor Controlled reactor</td>
</tr>
<tr>
<td>VAR</td>
<td>Volt ampere reactive</td>
</tr>
<tr>
<td>VSC</td>
<td>Voltage source converter</td>
</tr>
<tr>
<td>WECS</td>
<td>Wind energy conversion system</td>
</tr>
<tr>
<td>Z</td>
<td>Zero</td>
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