# CONTROL OF SOLAR PV-BES-WIND BASED STANDALONE AND GRID CONNECTED AC MICROGRIDS WITH SYNCHRONIZATION

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By

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***Submitted***

***in fulfilment of the requirement of the degree of*** **Doctor of Philosophy**

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# CERTIFICATE

It is certified that the thesis entitled "**Control of Solar PV-BES-Wind Based Standalone and Grid Connected AC Microgrids with Synchronization**," being submitted by **Mr. Gaurav Modi** for award of the degree of **Doctor of Philosophy** in the Department of Electrical Engineering, Indian Institute of Technology Delhi, is a record of the student work carried out by him under my supervision and guidance. The matter embodied in this thesis has not been submitted for award of any other degree or diploma.

**Dated:**

**(Prof. Bhim Singh)**
**Electrical Engineering Department**
**Indian Institute of Technology Delhi**
**Hauz Khas, New Delhi-110016, India**

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**Dated:**

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# ABSTRACT

This thesis presents a comprehensive approach to controlling solar PV-BES-wind-based standalone and grid-connected AC microgrids with synchronization. Throughout this research, various configurations pertaining to solar PV-based microgrids are investigated, taking into account the specific needs of low and medium-income consumers in both urban and rural settings. Furthermore, the exploration of microgrid configurations is expanded to include solar PV-BES-wind-based systems, leading to the development of a novel structure that optimizes the benefits of existing frameworks in a cost-effective manner. Additionally, the thesis delves into the feasibility of employing synchronous reluctance generators (SyRGs) as a cost-effective alternative to PMSGs for small-scale WES, further enhancing the affordability and accessibility of renewable energy solutions.

To confront emerging power quality challenges stemming from nonlinear loads, this thesis devises innovative control strategies. These strategies leverage the architecture of traditional control algorithms, providing effective solutions with ease of implementation. In response to synchronization challenges, the thesis introduces improved filter algorithms that demonstrate enhanced responsiveness while maintaining low computational complexity. Consequently, these advancements address the limitations inherent in existing synchronization algorithms.

Furthermore, power management schemes are meticulously crafted to align with specific consumer and application needs, considering practical constraints of system. These schemes encompass a range of aspects, including providing grid support by ensuring that any increase in PCC voltage remains within predefined standards.

In the context of DG-based standalone microgrids, this thesis proposes innovative control strategies based on multimode operation to minimize the utilization of DG sets. These strategies entail the operation of microgrids in both standalone mode and DG-connected mode, with the latter being activated exclusively during emergencies. Upon the microgrid's ability to fulfil load demand through RES and BES, the DG-connected mode is promptly deactivated. To address technical challenges associated with seamlessly transitioning microgrid operation between different modes in multimode operation-based grid-connected microgrids, robust and straightforward solutions are developed. Furthermore, these solutions are extended to DG-based standalone microgrids to facilitate seamless transitions between standalone operational mode and DG-connected mode.

To validate the performance of the proposed microgrid configurations and engineered control strategies, simulations are conducted using MATLAB/Simulink in MATLAB 2017B software.

The response of the microgrids and their controls is thoroughly examined in this virtual environment. Subsequently, hardware implementation and real-time analysis are employed to further investigate the performance of the configured microgrids and their control strategies, aiming to validate the simulated results. The obtained findings conclusively demonstrate the successful achievement of the defined objectives outlined in this thesis work.

# सार

इस शोध प्रबंध में सौर फोटोवोल्टाइक, बैटरी ऊर्जा भंडारण और पवन-आधारित स्टैंडअलोन और ग्रिड से जुड़े एसी माइक्रोग्रिड्स के नियंत्रण के लिए एक व्यापक दृष्टिकोण प्रस्तुत किया गया है। इस शोध के दौरान, शहरी और ग्रामीण दोनों क्षेत्रों में निम्न और मध्यम आय वाले उपभोक्ताओं की विशेष आवश्यकताओं को ध्यान में रखते हुए सौर पीवी-आधारित माइक्रोग्रिड्स के विभिन्न कॉन्फ़िगरेशन की जांच की गई है। इसके अलावा, माइक्रोग्रिड कॉन्फ़िगरेशन की खोज को सौर पीवी-बैटरी ऊर्जा भंडारण-पवन-आधारित प्रणालियों तक विस्तारित किया गया है, जिसके परिणामस्वरूप एक नए ढांचे का विकास हुआ है जो मौजूदा फ्रेमवर्क के लाभों को एक लागत-प्रभावी तरीके से अनुकूलित करता है। इसके अतिरिक्त, इस शोध प्रबंध में छोटे पैमाने के पवन ऊर्जा प्रणाली के लिए स्थायी चुंबक सिंक्रोनस जनरेटर के लागत-प्रभावी विकल्प के रूप में सिंक्रोनस रीलक्टेंस जनरेटर के उपयोग की व्यवहार्यता की जांच की गई है, जिससे नवीकरणीय ऊर्जा समाधानों की पहुंच और अधिक किफायती बन सके।

गैर-रैखिक लोड से उत्पन्न हो रही उभरती हुई बिजली की गुणवत्ता की चुनौतियों का सामना करने के लिए, इस शोध प्रबंध में नवाचारपूर्ण नियंत्रण रणनीतियाँ तैयार की गई हैं। ये रणनीतियाँ पारंपरिक नियंत्रण एल्गोरिदम की संरचना का लाभ उठाती हैं, जिससे उन्हें प्रभावी ढंग से लागू करना आसान होता है। सिंक्रोनाइज़ेशन चुनौतियों के प्रति प्रतिक्रिया में, शोध प्रबंध में बेहतर फिल्टर एल्गोरिदम पेश किए गए हैं जो कम कम्प्यूटेशनल जटिलता बनाए रखते हुए बेहतर प्रतिक्रिया क्षमता प्रदर्शित करते हैं। नतीजतन, ये प्रगति मौजूदा सिंक्रोनाइज़ेशन एल्गोरिदम की अंतर्निहित सीमाओं को संबोधित करती है।

इसके अलावा, उपभोक्ता और अनुप्रयोग की विशिष्ट आवश्यकताओं के अनुरूप पावर प्रबंधन योजनाएं सावधानीपूर्वक तैयार की जाती हैं, जो सिस्टम की व्यावहारिक बाधाओं को ध्यान में रखते हुए होती हैं। इन योजनाओं में पॉइंट ऑफ़ कॉमन कप्लिंग वोल्टेज में किसी भी वृद्धि को पूर्वनिर्धारित मानकों के भीतर बनाए रखते हुए ग्रिड समर्थन प्रदान करना शामिल है।

डीजल जनरेटर आधारित स्टैंडअलोन माइक्रोग्रिड्स के संदर्भ में, इस शोध प्रबंध में मल्टीमोड ऑपरेशन के आधार पर डीजल जनरेटरों के उपयोग को कम करने के लिए नवाचारी नियंत्रण रणनीतियों का प्रस्ताव किया गया है। इन रणनीतियों में माइक्रोग्रिड्स को स्टैंडअलोन मोड और डीजल जनरेटर कनेक्टेड मोड दोनों में संचालित करना शामिल है, जिसमें बाद वाला केवल आपातकालीन स्थितियों में सक्रिय होता है। जैसे ही माइक्रोग्रिड नवीकरणीय ऊर्जा स्रोतों और बैटरी ऊर्जा भंडारण के माध्यम से लोड मांग को पूरा करने में सक्षम होता है, डीजल जनरेटर कनेक्टेड मोड को तुरंत निष्क्रिय कर दिया जाता है। मल्टीमोड ऑपरेशन-आधारित ग्रिड से जुड़े माइक्रोग्रिड्स में विभिन्न मोड के बीच सुगम संक्रमण के साथ संबंधित

तकनीकी चुनौतियों को संबोधित करने के लिए, मजबूत और सरल समाधान विकसित किए गए हैं। इसके अलावा, ये समाधान डीजल जनरेटर आधारित स्टैंडअलोन माइक्रोग्रिड्स तक विस्तारित किए गए हैं ताकि स्टैंडअलोन ऑपरेशनल मोड और डीजल जनरेटर कनेक्टेड मोड के बीच सुगम संक्रमण की सुविधा हो सके।

प्रस्तावित माइक्रोग्रिड कॉन्फ़िगरेशन और डिज़ाइन किए गए नियंत्रण रणनीतियों के प्रदर्शन को मान्य करने के लिए, मैटलैब 2017बी सॉफ़्टवेयर में MATLAB/Simulink का उपयोग करके सिमुलेशन किए गए हैं। इस आभासी वातावरण में माइक्रोग्रिड्स और उनके नियंत्रण की प्रतिक्रिया की पूरी तरह से जांच की गई है। इसके बाद, हार्डवेयर कार्यान्वयन और वास्तविक समय विश्लेषण का उपयोग करके कॉन्फ़िगर किए गए माइक्रोग्रिड्स और उनकी नियंत्रण रणनीतियों के प्रदर्शन की आगे की जांच की गई है, जिसका उद्देश्य सिमुलेशन परिणामों को मान्य करना है। प्राप्त निष्कर्ष स्पष्ट रूप से इस शोध कार्य में उल्लिखित परिभाषित उद्देश्यों की सफल उपलब्धि को प्रदर्शित करते हैं।

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ADC | Analog-to-Digital Converter |
| BDDC | Bidirectional DC-DC Converter |
| BES | Battery Energy Storage |
| BTC | Boost Converter |
| CCA | Current Control Algorithm |
| CDSC | Cascaded Delay Signal Cancellation |
| C-LMS | Cascaded Least Mean Square |
| CNF | Complex Notch Filter |
| CPG | Constant Power Generation |
| CSOGI | Cascaded Second Order Generalized Integrator |
| DAC | Digital-to-Analog Converter |
| DBR | Diode Bridge Rectifier |
| DFIG | Doubly-Fed Induction Generator |
| DG | Diesel Generator |
| DSC | Delay Signal Cancellation |
| DSO | Digital Signal Oscilloscope |
| FAC | Fundamental Active Component |
| FEZ | Fuel Economy Zone |
| FLL | Frequency-Locked Loop |
| F-LMS | Fractional Least Mean Square |
| FSP | Fractional Signal Processing |
| GSC | Grid Side Converter |
| HDN | Harmonic Decoupling Network |
| HPF | High-Pass Filter |
| I-CSOGI | Improved Cascaded Second Order Generalized Integrator |
| IGBT | Insulated Gate Bipolar Transistor |
| INC | Incremental Conductance |
| ISOGI | Improved Second Order Generalized Integrator |
| LCFs | Load Compensation Features |
| LMS | Least Mean Square |
| L-SOGI | Low-Pass Second Order Generalized Integrator |
| MAF | Moving Average Filter |
| MCCF | Multiple Complex Coefficient Filter |
| MMSE | Minimum Mean Square Error |
| MNF-SOGI | Modified Notch Filter-based Second Order Generalized Integrator |
| MNSOGI | Modified Novel Second Order Generalized Integrator |
| MPP | Maximum Power Point |
| MPPT | Maximum Power Point Tracking |
| MSC | Machine Side Converter |
| MSOGI | Multiple Second Order Generalized Integrator |
| MSTOGI | Mixed Second and Third-Order Based Generalized Integrator |

| | |
|---|---|
| NFOGI | Novel Fourth-Order Generalized Integrator |
| NLMS | Normalized Least Mean Square |
| NSC | Negative Sequence Component |
| OSG | Orthogonal Signal Generator |
| PCC | Point of Common Coupling |
| PCU | Power Conditioner Unit |
| PEC | Power Electronic Converter |
| PES | Power Electronics Switches |
| PI | Proportional Integrator |
| PGSC | PV Grid Side Converter |
| PLL | Phase-Locked Loop |
| PMS | Power Management Scheme |
| PMSG | Permanent Magnet Synchronous Generator |
| P&O | Perturb and Observe |
| PQ | Power Quality |
| PQA | Power Quality Analyzer |
| PR | Proportional Resonant |
| PSC | Positive Sequence Component |
| PWM | Pulse Width Modulation |
| QT1-PLL | Quasi-Type-1 Phase-Locked Loop |
| RES | Renewable Energy Sources |
| ROGI | Reduce Order Generalized Integrator |
| SCIG | Squirrel Cage Induction Generator |
| SD | Steepest Descent |
| SG | synchronous Generator |
| SOGI | Second Order Generalized Integrator |
| SPV | Solar Photovoltaic |
| SPVS | Solar Photovoltaic System |
| SRFT | Synchronous Rotating Frame Theory |
| STS | Static Transfer Switches |
| SyRG | Synchronous Reluctance Generator |
| SyRM | Synchronous Reluctance Motor |
| TOGI | Third-Order Generalized Integrator |
| UPF | Unity Power Factor |
| UPS | Uninterruptible Power Supply |
| UTV | Unit Template Vectors |
| VCA | Voltage Control Algorithm |
| VSC | Voltage Source Converter |
| WES | Wind Energy System |
| WG | Wind Generator |
| WGSC | Wind Grid Side Converter |
| WT | Wind Turbine |
| WTGA | Wind Turbine Generator Assembly |

# LIST OF SYMBOLS

| | |
|---|---|
| $B_{SOC}$ | Charge status of BES. |
| $B_{SOC\_min}$ and $B_{SOC\_max}$ | Set minimum and maximum limits for charge status of BES |
| $C_{dc1}$ and $C_{dc2}$ | DC link capacitor of PGSC and WGSC |
| $d_{BDDC}$ and $d_{BTC}$ | Duty ration of BDDC and BTC |
| $e_{MPPT}$, $e_{CPG}$ | Estimated error for MPPT and CPG operation of BTC |
| $f_{DG}$, $f_G$, $f_L$ | Frequency of DG set voltage, AC grid voltage and PCC voltage |
| $I_B$, $V_{BN}$, $C_B$ | Sensed current, nominal voltage, and rated AH capacity of BES |
| $I_{BR}$ | Reference BES current |
| $I_{Bmax\_C}$ and $I_{Bmax\_D}$ | Maximum allowable charging and discharging currents of BES |
| $\Delta I_B$ | Current perturbation used in estimation reference current for BES |
| $i_{DGa}$, $i_{DGb}$, $i_{DGc}$ | DG set currents |
| $i_{DGa}^*$, $i_{DGb}^*$, $i_{DGc}^*$ | Reference DG set currents |
| $i_{DGdr}$, $i_{DGqr}$ | dq components of reference DG set currents |
| $i_{Ga}$, $i_{Gb}$, $i_{Gc}$ | AC grid currents |
| $i_{Ga}^*$, $i_{Gb}^*$, $i_{Gc}^*$ | Reference AC grid currents |
| $I_{Gn}^*$ | Reference current of AC grid neutral wire |
| $I_{Gd}^*$, $I_{Gq}^*$ | d-q components reference AC grid currents |
| $i_{La}$, $i_{Lb}$, $i_{Lc}$ | Local load currents |
| $i_{L\alpha}$, $i_{L\beta}$ | Two-phase or αβ axis current of local load currents |
| $i_{La1}^+$, $i_{Lb1}^+$, $i_{Lc1}^+$ | Filtered PSC of load current |
| $i_{L\alpha1}^+$, $i_{L\beta1}^+$ | Filtered PSC of αβ axis current of local load currents |
| $I_{Ld}$, $I_{Lq}$ | d-q components of sensed load current |
| $I_{Ld1}$, $I_{Lq1}$ | Ripple free d-q components of load current |
| $i_{FACa}$, $i_{FACb}$, and $i_{FACc}$ | Amplitudes of fundamental active components of load currents |
| $I_{L1}$ | Average of computed amplitudes of FAC of load currents |
| $I_{Loss}$/$I_{Loss1}$ | Loss component of PGSC |
| $I_{Loss2}$ | Loss component of WGSC |
| $i_{PGSCa}$, $i_{PGSCb}$, $i_{PGSCc}$ | PGSC currents |
| $I_{SC}$, $I_{MPP}$, $I_{PV}$ | Short circuit current, MPP current and sensed current of SPV array |
| $I_{PVref}$ | Reference SPV array current |
| $I_{sw}$ and $V_{sw}$ | Current and voltage rating of VSC's switch |
| $i_{WGSCa}$, $i_{WGSCb}$, $i_{WGSCc}$ | WGSC currents |
| $i_{\omega ga}$, $i_{\omega gb}$, $i_{\omega gc}$ | Wind generator currents |
| $i_{\omega g\alpha}$, $i_{\omega g\beta}$ | αβ components of stator currents of SyRG based wind generator |
| $i_{\omega ga}^*$, $i_{\omega gb}^*$, $i_{\omega gc}^*$ | Reference wind generator currents |
| $I_{d\omega g}^*$, $I_{q\omega g}^*$ | dq components of reference wind generator currents |
| $i_{Gn}$, $i_{Ln}$, $i_{PGSCn}$ | Neutral wire or 4$^{th}$ wire currents of AC grid, local load and PGSC |
| $I_{rr}$ | Solar irradiation |
| $I_{PV\_AC}$, $I_{WG\_AC}$ | AC equivalent current corresponding to power generated by SPV array and WG |
| $L_f$ | Interfacing inductor |

| | |
|---|---|
| $L_{fn}$ | Interfacing inductor of PGSC's 4$^{th}$ leg. |
| $L_{BTC}$ and $L_{BDDC}$ | Inductors of BTC and BDDC. |
| $P_B$ and $P_L$ | Estimated powers of BES and local load |
| $P_{DG}$ and $Q_{DG}$ | Estimated active and reactive powers of DG set |
| $P_G$ and $Q_G$ | Estimated active and reactive powers of AC grid |
| $P_{PV}$ and $P_{WG}$ | Estimated powers of SPV array and WG |
| $P_{GEN}$ | Total generated power by SPV array and WG |
| $P_{WT}$ | Generated mechanical power from wind turbine |
| $P_{Bmax}$ | Maximum charging power capacity of BES |
| $P_{BR}$ | Reference power for BES |
| $P_{GR}$, $Q_{GR}$ | Reference active and reactive powers for AC grid |
| $P_{G\_max}$ | Injected maximum power into AC grid during CPG operation of SPV system |
| $P_{PVM}$ | Signal used to control operation of SPV array in MPPT and off-MPPT modes |
| $R_f$-$C_f$ | R-C filter |
| $S_{LCFs}$ | Signal to active load compensation features in GSC |
| $S_{BDDC}$, $S_{BTC}$ | Gating signals of BDDC and BTC |
| $S_{PGSC}$, $S_{WGSC}$, $S_{MSC}$ | Gating signals of PGSC, WGSC and MSC |
| $T_{WT}$ | Wind turbine torque |
| $T_{\omega g}$, $T_{\omega gest}$, $T_{\omega g}^*$ | Actual, estimated and reference torque of SyRG based WG |
| $u_{Ga}$, $u_{Gb}$, $u_{Gc}$ | In-phase per-unit phase voltages or UTV of AC grid phase voltages |
| $u_{Gaq}$, $u_{Gbq}$, $u_{Gcq}$ | Quadrature per-unit phase voltages of AC grid phase voltages |
| $u_{La}$, $u_{Lb}$, $u_{:c}$ | In-phase per-unit phase voltages or UTV of PCC phase voltages |
| $V_{dc}$/$V_{dc1}$, $V_{dcref}$/$V_{dcref1}$ | Sensed DC link voltage of PGSC and its corresponding reference |
| $V_{dc2}$, $V_{dcref2}$ | Sensed DC link voltage of WGSC and its corresponding reference |
| $v_{DGab}$, $v_{DGbc}$, $v_{DGca}$ | DG set line voltages |
| $v_{Gab}$, $v_{Gbc}$, $v_{Gca}$ | AC grid line voltages |
| $v_{Ga}$, $v_{Gb}$, $v_{Gc}$ | AC grid phase voltages |
| $v_{G\alpha}$, $v_{G\beta}$ | Two-phase or αβ axis voltages of AC grid phase voltages |
| $v_{G\alpha 1}$, $v_{G\beta 1}$ | Filtered in phase components of $v_{G\alpha}$, $v_{G\beta}$ |
| $v_{G\alpha q1}$, $v_{G\beta q1}$ | Filtered in quadrature components of $v_{G\alpha}$, $v_{G\beta}$ |
| $v_{G\alpha 1}^+$, $v_{G\beta 1}^+$ | Filtered PSC of αβ axis voltages of AC grid phase voltages |
| $v_{Lab}$, $v_{Lbc}$, $v_{Lca}$ | PCC line voltages |
| $v_{La}$, $v_{Lb}$, $v_{Lc}$ | PCC phase voltages |
| $v_{L\alpha}$, $v_{L\beta}$ | Two-phase or αβ axis voltages of PCC phase voltages |
| $v_{L\alpha 1}$, $v_{L\beta 1}$ | Filtered in phase components of $v_{L\alpha}$, $v_{L\beta}$ |
| $v_{L\alpha q1}$, $v_{L\beta q1}$ | Filtered in quadrature components of $v_{L\alpha}$, $v_{L\beta}$ |
| $v_{L\alpha 1}^+$, $v_{L\beta 1}^+$ | Filtered PSC of αβ axis voltages of AC grid phase voltages |
| $v_{La}^*$, $v_{Lb}^*$, $v_{Lc}^*$ | Reference PCC voltages |
| $V_{Lm}^*$, $\theta_L^*$ | Amplitude and phase of reference PCC voltages |
| $V_{L\_syn}$ and $\theta_{L\_syn}$ | Amplitude and phase of reference PCC voltages for synchronization |
| $v_{L\alpha}$, $v_{L\beta}$ | Two-phase or αβ axis voltages of PCC phase voltages |

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|---|---|
| $V_{DGm}$, $V_{Gm}$, $V_{Lm}$ | Estimated amplitude of phase voltage for DG set, AC grid and PCC |
| $V_{max}$ | Predefined maximum limit for PCC voltage |
| $V_{oc}$, $V_{MPP}$, $V_{PV}$ | Open circuit voltage, MPP voltage and sensed voltage of SPV array |
| $V_{PVref}$ | Reference SPV array voltage |
| $\Delta V_{PVr}$ | Voltage perturbation used in estimation of $V_{PVref}$ |
| $V_W$ | Wind speed |
| $v_{\omega g\alpha}$, $v_{\omega g\beta}$ | αβ components of stator voltages of SyRG based wind generator |
| $X_{Syn}$ | Synchronization signal |
| $X_{DG}$, $X_G$ | Signal representing status of DG set and AC grid |
| $f_{samp}$ | Sampling frequency |
| $\theta_{DG}$, $\theta_G$, $\theta_L$ | Estimated phase angle of DG set, AC grid and PCC voltages |
| $\theta_{\omega gest}$ | Estimated rotor position of SyRG based wind generator |
| $K$ | Constant for controlling C-rate of BES |
| $k_{pVdc}/k_{pVdc1}$, $k_{iVdc}/k_{iVdc1}$ | Gains of DC link PI regulator in PGSC control |
| $k_{pVdc2}$, $k_{iVdc2}$ | Gains of DC link PI regulator in WGSC control |
| $k_{pr\_PGSC}$, $k_{ir\_PGSC}$ | Gains of PR regulator in PGSC control |
| $k_{pVPV}$, $k_{iVPV}$ | Gains of PI regulator in BTC control |
| $k_{pV\_BDDC}$, $k_{iV\_BDDC}$ | Gains of BDDC's outer PI controller loop |
| $k_{pI\_BDDC}$, $k_{iI\_BDDC}$ | Gains of BDDC's inner PI controller loop |
| $k_{p\_\omega g}$, $k_{i\_\omega g}$ | Gains of speed PI regulator in MSC control. |
| $\Delta I_{PGSC\_pp}$, $\Delta I_{WGSC\_pp}$ | Peak to peak ripple in PGSC and WGSC currents |
| $\alpha_L$ | Gain of LMS algorithm. |
| $\alpha_F$, $\chi$ | Gains of fractional component of F-LMS algorithm |
| $C_P$ and $C_t$ | Power and torque coefficients of wind turbine |
| $\lambda$ *and* $\beta$ | Tip speed ratio and pitch angle of wind turbine |
| $c_1$, $c_2$, $c_3$, $c_4$, $c_5$, $c_6$ | Design constants of wind turbine |
| $G_{WT}$, $r_{WT}$, $\omega_{WT}$ | Gear box ration, blade radius and rotational speed of wind turbine |
| $\omega_g$, $\omega_{gest}$, $\omega_{gref}$ | Actual, estimated and reference speeds or SyRG-based WG |
| $\lambda_{opt}$, $\omega_{gopt}$ | Optimum TSR and speed of wind generator for MPPT operation |
| $L_d$, $L_q$ | Direct and quadrature axis inductances of SyRG-based WG |
| $r_{\omega g}$ | Winding resistance of SyRG-based WF |
| $T_w$ and $N$ | Window length of MAF and delay length |
| $\Psi_{\omega g\alpha}$, $\Psi_{\omega g\beta}$ | αβ components of stator fluxes of SyRG based wind generator |
| $i_{Lhr}$ | Harmonics and negative sequence currents of local load |