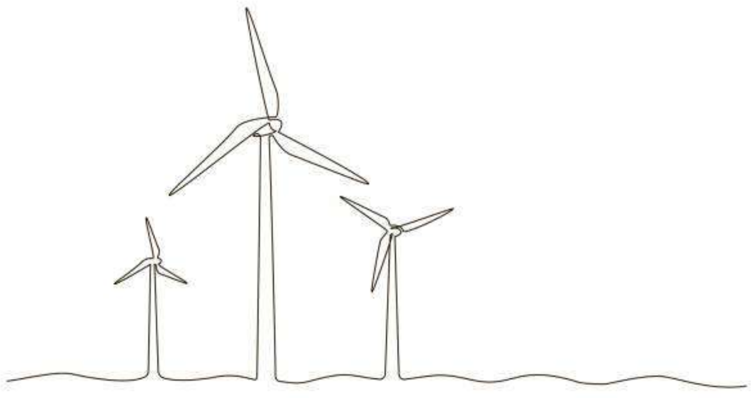
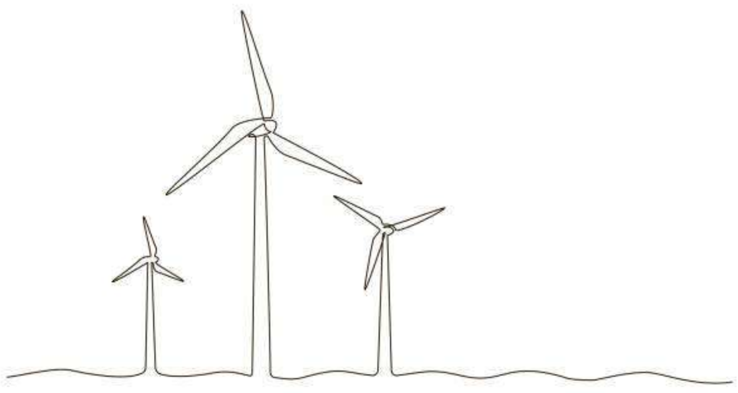
Opportunities and Challenges in New Markets for Offshore Wind Energy

South Asian Association for Regional Cooperation (SAARC) Webinar





presentation by

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SAARC

S A A R C
SOUTH ASIAN ASSOCIATION
FOR REGIONAL COOPERATION

World: Wind Energy Installed Capacity

Installed Capacity [1]

- Global wind power capacity: 1,173.5 GW (which is nearly 10% of total electricity demand).
- Onshore wind power capacity: 1088.5 GW.
- Offshore wind power capacity: 83GW.

Plan for Future Offshore Wind Energy [1]

As per IRENA's Planned Energy Scenario (PES), global offshore capacity is projected to rise

- 275 GW by 2030.
- 1200 GW by 2050.

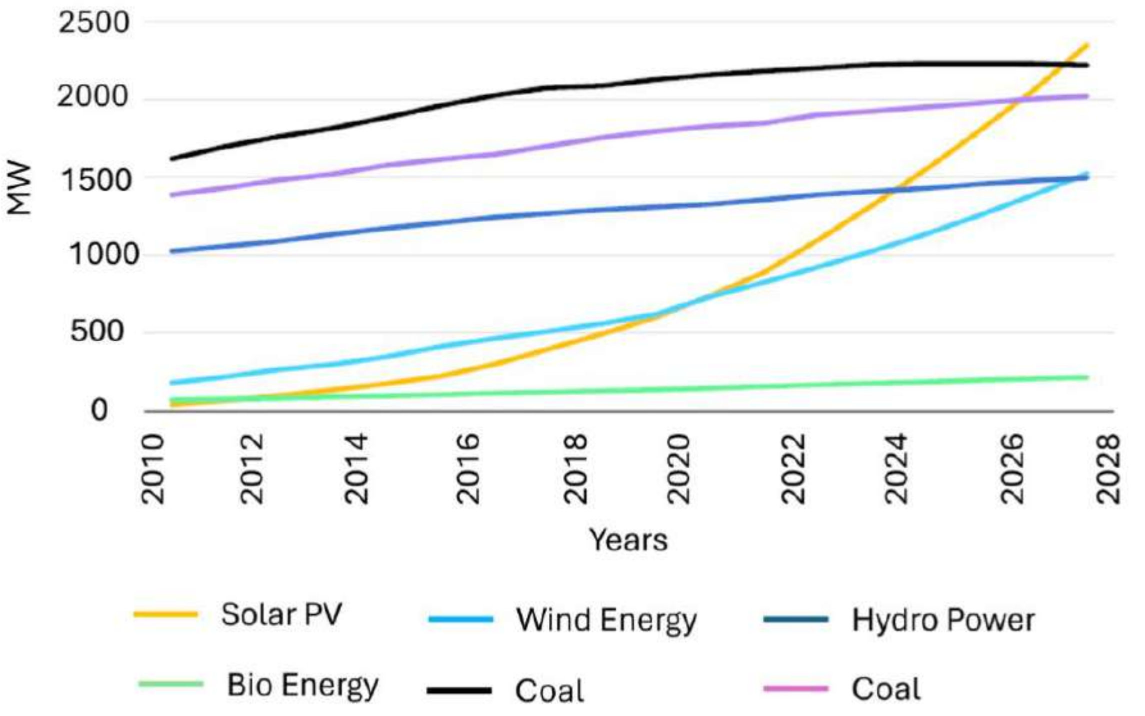


Fig.1 Global installed capacity share by technology[2].

[1] Renewable capacity statistics 2025. (2025, March 1). https://www.irena.org/Publications/2025/Mar/Renewable-Capacity-Statistics-2025
[2] Iea, "renewable 2022 - analysis and forecast to 2027," International Energy Agency, Paris, Tech. rep., 2022," accessed:2025-11-10. [Online]. Available: https://iea.blob.core.windows.net/assets/ada7af90-e280-46c4-a577-df2e4fb44254/Renewables2022.pdf.

Asia Pacific: Wind Energy Installed Capacity

Installed Capacity [3]

- Total wind energy capacity: 785 GW
- Onshore wind power capacity: 780MW
- Offshore wind power capacity: 5 GW

Fig. 2 Asia Pacific region [4].

[3] Exec-Summary_APAC-Offshore-Wind-2025.pdf
[4] https://c4scourses.in/wp-content/uploads/2025/03/image-53.png

South Asia: Wind Energy Installed Capacity

Installed Capacity [1]

- Total wind energy capacity: 53 GW
- Onshore wind power capacity: 53 GW
- Offshore wind power capacity: 0 GW

Country Comes Under South Asia Region

- Afghanistan (offshore wind energy potential: No)
- Bangladesh (Yes)
- Bhutan (No)
- India (Yes)
- Maldives (Yes)
- Nepal (No)
- Pakistan (Yes)
- Sri Lanka (Yes)

Fig. 3 South Asia region [5].

[5] https://upload.wikimedia.org/wikipedia/commons/e/e3/South_Asia_%28orthographic_projection%29_without_national_boundaries.svg

South Asia Wind Energy Capacity Comparison

Table I: Comparative study of installed wind energy in South Asia [1]

Country	Onshore wind installed capacity	Offshore wind installed capacity	Total wind capacity	Updates (2024–2025)
India	≈ 52.1 GW	0 GW	≈ 52.1 GW	Offshore auctions planned (37 GW by 2030), no operational offshore yet
Pakistan	≈ 1.84 GW	0 GW	≈ 1.84 GW	All wind farms are onshore (Jhimpir, Gharo corridor)
Bangladesh	≈ 62.9 MW	0 MW	≈ 62.9 MW	500 MW offshore project approved (feasibility phase)
Sri Lanka	15 MW	0 MW	15 MW	Small test installations; offshore potential under study
Nepal	0 MW	0 MW	0 MW	No grid-scale wind; micro-wind projects only
Bhutan	0 MW	0 MW	0 MW	Focus is on hydropower; wind potential low
Maldives	≈ 0.6 MW	0 MW	≈ 0.6 MW	Small turbine installations on islands
Afghanistan	0 MW	0 MW	0 MW	

Offshore Wind Energy Potential in SAARC Countries

Table II: Comparative study of offshore wind energy potential in SAARC countries

Country	Offshore wind energy potential
India [6]	70-74 GW
Pakistan [7]	50 GW
Bangladesh [8]	10 GW
Sri Lanka [9]	56 GW
Nepal [10]	0 MW
Bhutan [10]	0 MW
Maldives [10]	0 MW
Afghanistan [10]	0 MW

[6] https://tinyurl.com/ubmxm4sf
[7] https://tinyurl.com/3ru86mcv
[8] https://tinyurl.com/4tbt45j6
[9] https://tinyurl.com/bdfarv6n
[10] https://tinyurl.com/2zr857aj

Harsh Marine & Weather Conditions [11]

- Offshore sites face strong winds, high waves, storms, and corrosion.
- Weather restricts installation and maintenance windows, increasing delays and cost.

High Installation & Infrastructure Requirements [11]

- Requires specialised vessels, heavy-lift cranes, and deep-water ports.
- Foundations (monopile, jacket, floating) need precise geotechnical assessments.
- Cable-laying in deep/rough seabed conditions is technically demanding.

Electrical & Grid Integration Challenges [11]

- Long subsea cables introduce losses, require careful thermal design, and are prone to damage.
- Offshore substations must meet strict grid codes: FRT, reactive support, harmonics, etc.
- Synchronization, protection coordination, and SCADA integration are complex.

[11] https://www.gwec.net/reports/globaloffshorewindreport

Challenges in offshore Wind Turbine Technology

Higher Operation & Maintenance (O&M) Difficulty [11]

- Access to turbines is difficult due to sea states; vessels or helicopters are often required.
- Repairs and troubleshooting at sea are time-consuming and expensive.
- Reliability issues (gearbox, power converters, blades) have greater impact offshore.

Structural & Mechanical Fatigue [11]

- Continuous combined loading (wind + waves) leads to fatigue in blades, tower, drivetrain.
- Larger turbines (15–30 MW) face more complex dynamic behavior and resonance problems.

Environmental & Permitting Barriers [11]

- Long permitting cycles due to environmental impact assessments.
- Restrictions related to marine mammals, bird migration, fisheries, and seabed ecology.
- Noise constraints during piling require mitigation (bubble curtains, noise insulation)

Supply Chain Limitations [11]

- Limited global manufacturing for large blades, towers, and subsea cables.
- Shortage of installation vessels and port infrastructure slows deployment.
- Long lead times for critical components increase project risk.

High Capital & Financing Risk [11]

- Offshore projects require billions in upfront investment.
- Cost overruns due to weather delays or component shortages are common.
- Financing depends heavily on long-term stability of policies and power purchase agreements.

Technology Gaps (especially floating offshore wind) [11]

- Floating platforms require advanced mooring systems and dynamic cable designs.
- Long-term reliability of floating systems is still being validated.
- Integration with existing ports is complex due to platform size.

Health & Safety Challenges [11]

- Working at height, offshore transfers, and harsh conditions increase safety risks.
- Requires specialized training and emergency response planning.

Next-Generation Offshore Wind Turbines

- Larger turbine ratings: commercial turbines have grown from 5–8 MW to 14–18 MW, reducing cost per MW.
- Longer blades (100–120+ m) using carbon-fiber composites reduce weight while increasing swept area, leading to more wind energy harvesting.

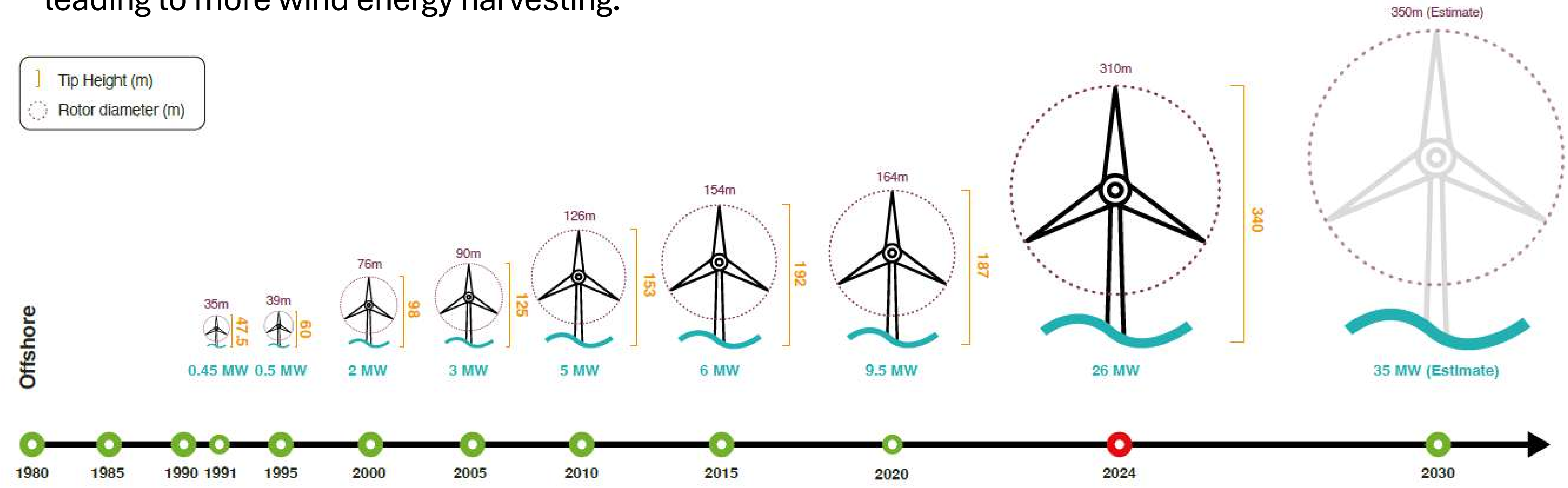


Fig. 4 Trend of Offshore turbine size, 1980-2030 [11].

Floating Offshore Wind Technology

- Enables deployment in deep waters (>60–100 m) where fixed-bottom turbines are impossible.
- Dynamic cables and flexible mooring lines adapted to platform movement.
- Floating platforms allow access to high-wind-speed regions far from shore.

Fig. 5 Floating Offshore Wind Technology [12].

[12] https://www.exsto.com/en/solutions/solutions-subsea/Floting-offshore-wind

Offshore Energy Hubs & Hybrid Systems

- Future offshore farms are evolving into multi-energy hubs, integrating:
- Offshore wind + offshore solar.
- Energy storage at sea.
- This allows stable and high-capacity energy export.

Fig. 6 Floating Offshore Wind Technology [13].

[13] https://www.euro-inox.org/how-european-wind-farms-are-revolutionizing-offshore-solar-integration/

Advanced SCADA & Cybersecurity

- High-resolution data acquisition with sub-second sampling.
- Secure, high-bandwidth fiber links for offshore communications.
- Real-time control for coordinated turbine-farm optimization.

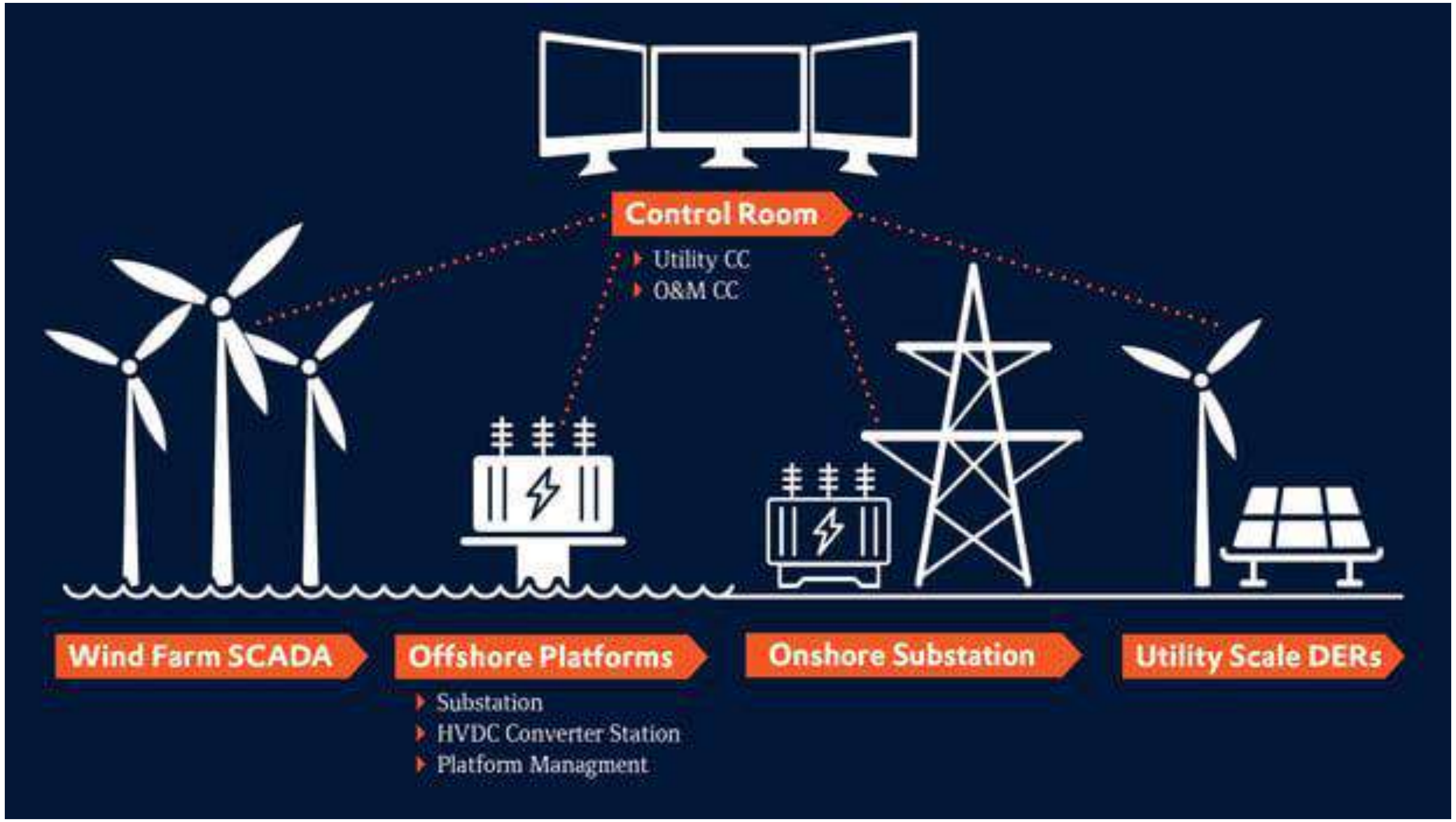


Fig. 7 Floating Offshore Wind Technology [14].

[14] https://www.copadata.com/en/industries/energy-infrastructure/energy-solutions/wind-energy-with-zenon/

Digitalization, Automation & Smart O&M

- Predictive maintenance using AI, machine learning, and digital twins reduces downtime.
- Condition monitoring systems (CMS) for blades, bearings, converters, and cables.
- Autonomous drones for blade inspection and offshore survey.
- Robotic crawlers for tower/blade inspection and underwater asset monitoring.

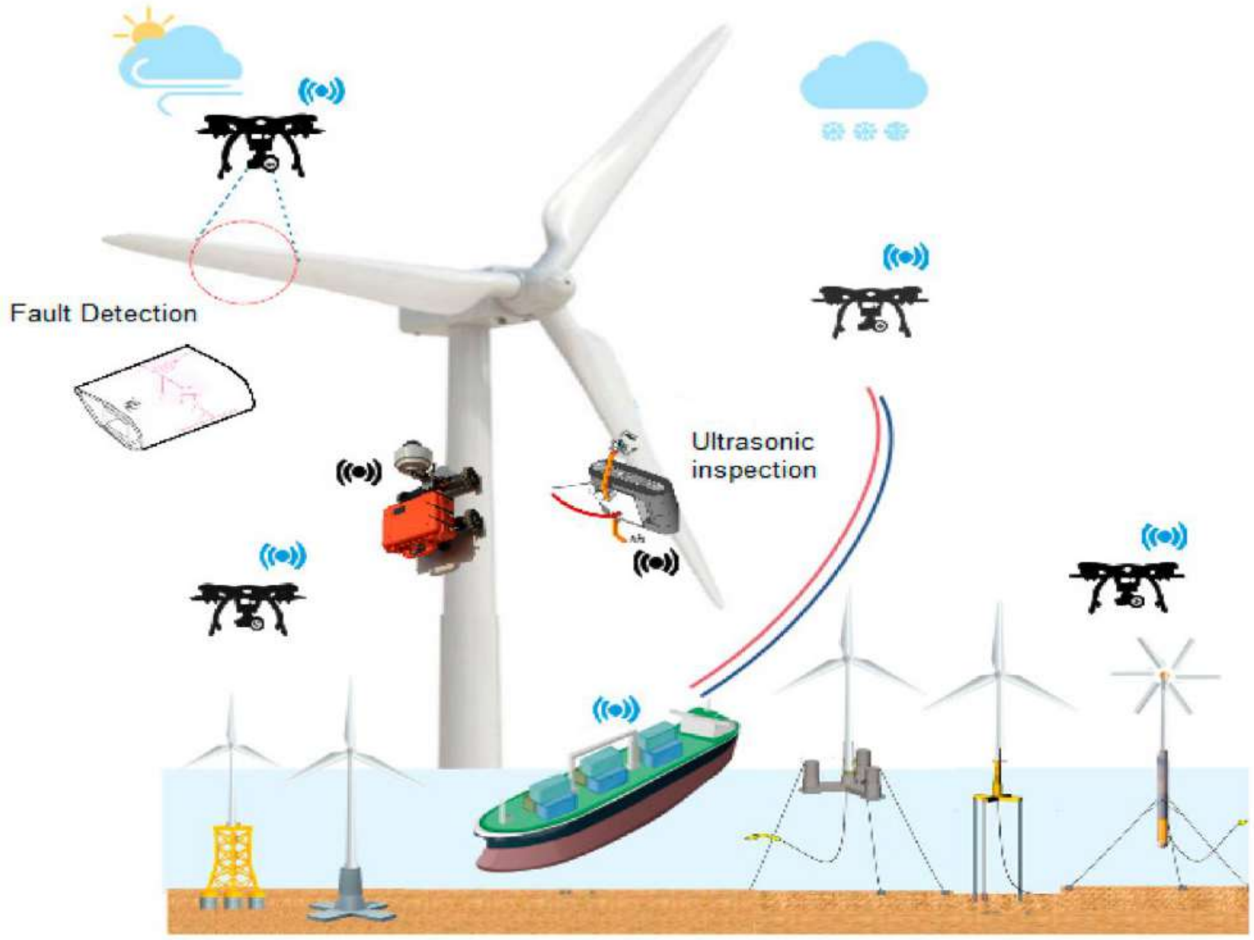


Fig. 8 Smart operation and maintenance technique [15].

[15] https://www.mdpi.com/2218-6581/10/1/26

Technology Advancements in Offshore Wind Energy

Energy Transmission and Grid Integration Innovations

- Offshore HVDC converter platforms enable long-distance power delivery with lower losses.
- Multi-terminal offshore HVDC grids are being developed for future energy hubs.
- High-capacity subsea cables with improved insulation and thermal performance.
- Advanced protection and control systems, including wide-area monitoring and fast fault ride-through.

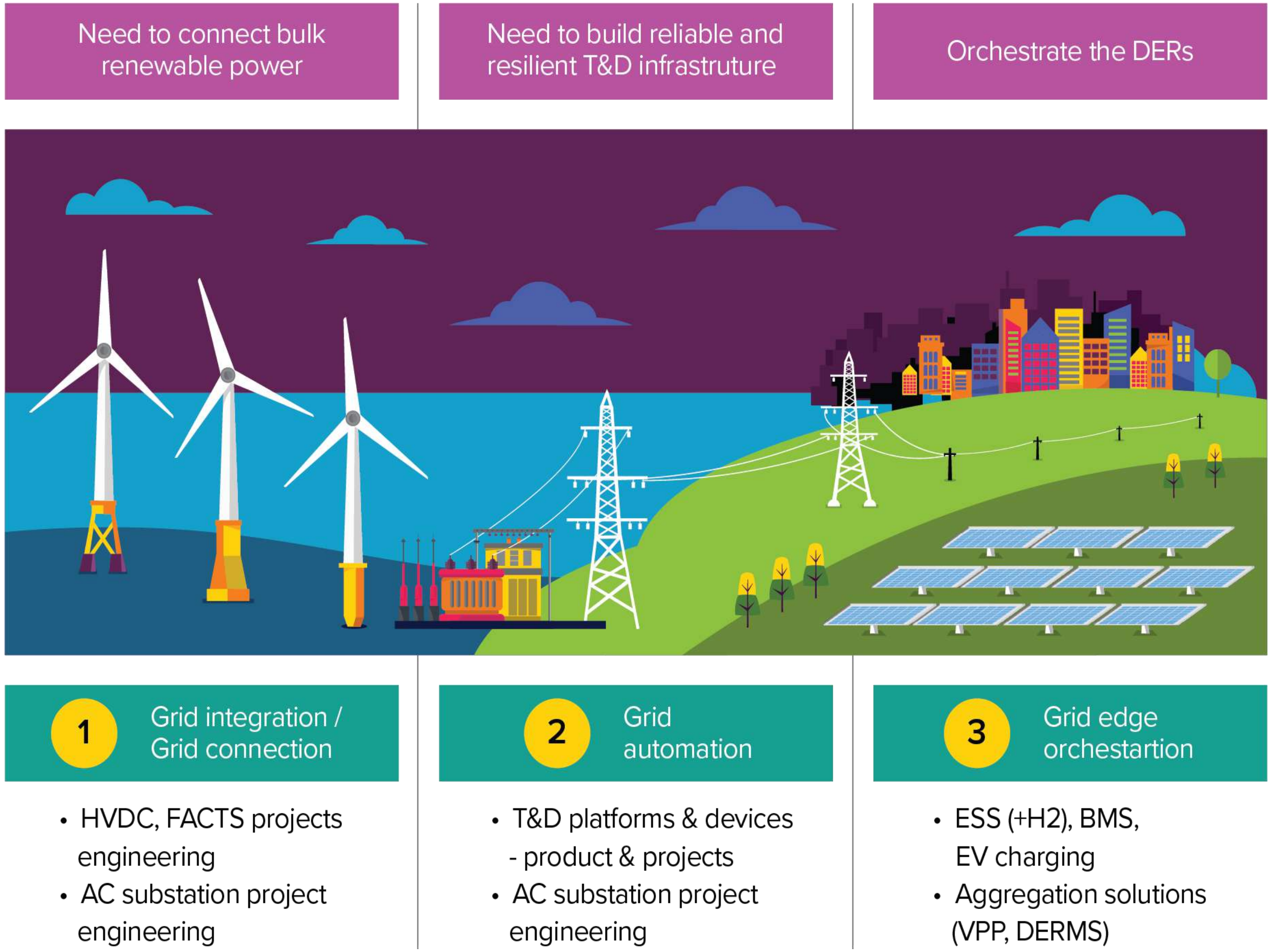


Fig. 9 Grid integration innovation [16]

[16] https://horizons.questglobal.com/accelerating-energy-transition-with-a-robust-power-grid-engineering-the-sustainable-resilient-and-smart-grid-of-the-future/

Technology Advancements in Offshore Wind Energy

Cost Reduction Technologies

- Standardized turbine components and mass manufacturing.
- Improved installation logistics and optimized vessel scheduling.
- Advanced project planning using 3D digital models and simulation.

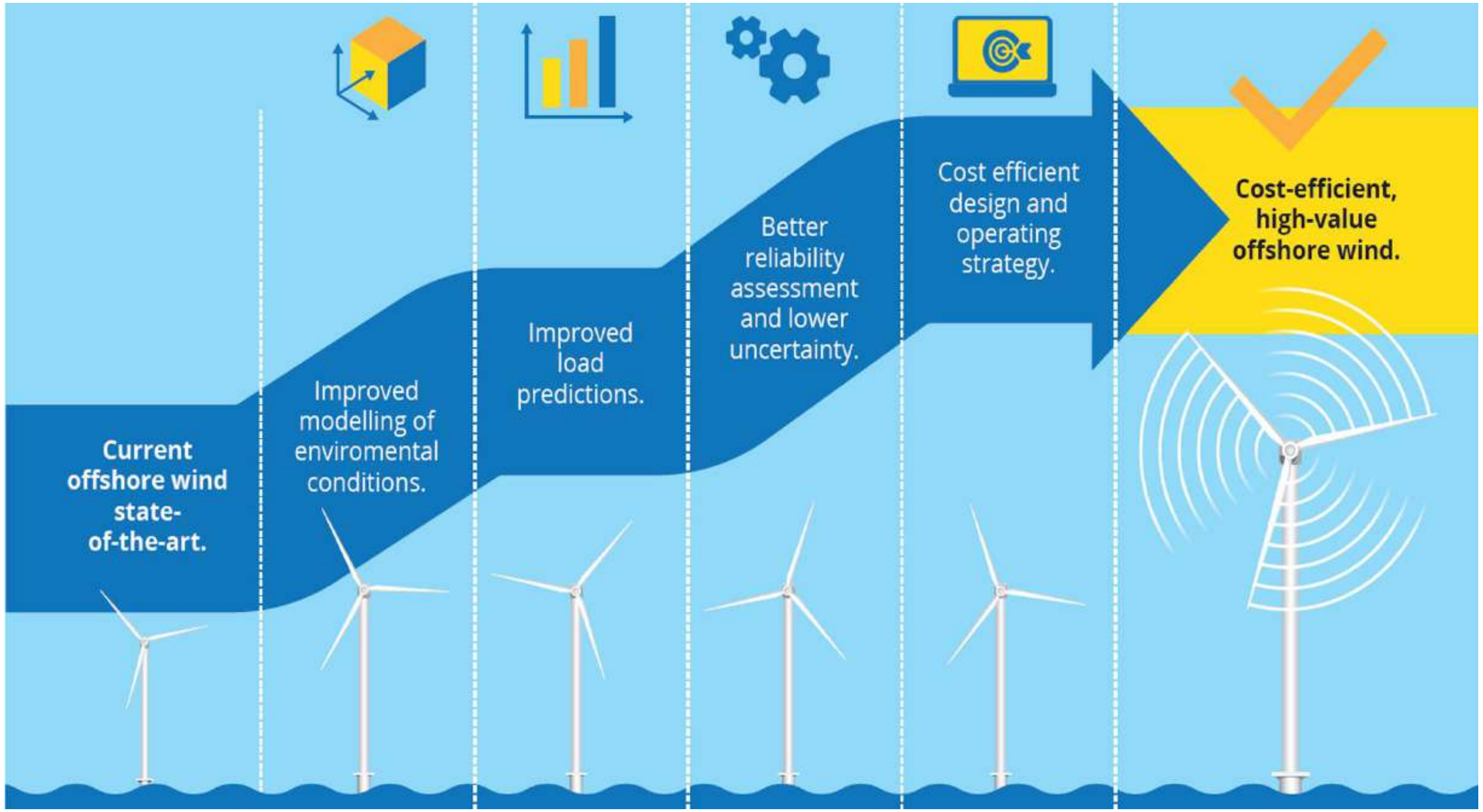


Fig.10 Cost reduction technology [17].

[17] https://wind.dtu.dk/newsarchive/2024/12/hiperwind-cuts-offshore-wind-energy-costs-by-up-to-9

Cost Reduction Technologies

- Total installation cost (TIC) values decrease with time due to technological advancements.
- However, offshore wind turbines are more costly compared to onshore technologies.

Fig. 11 Historical and projected global total installation cost (TIC) values [18].

[18] https://www.irena.org/Publications/2025/Jun/Renewable-Power-Generation-Costs-in-2024

Environmental & Noise Mitigation Technologies

- Bubble curtain systems and vibro-piling reduce underwater noise during installation.
- Bird detection radars and AI-based wildlife monitoring systems reduce ecological impact.
- Low-noise blade designs to minimize acoustic emissions.

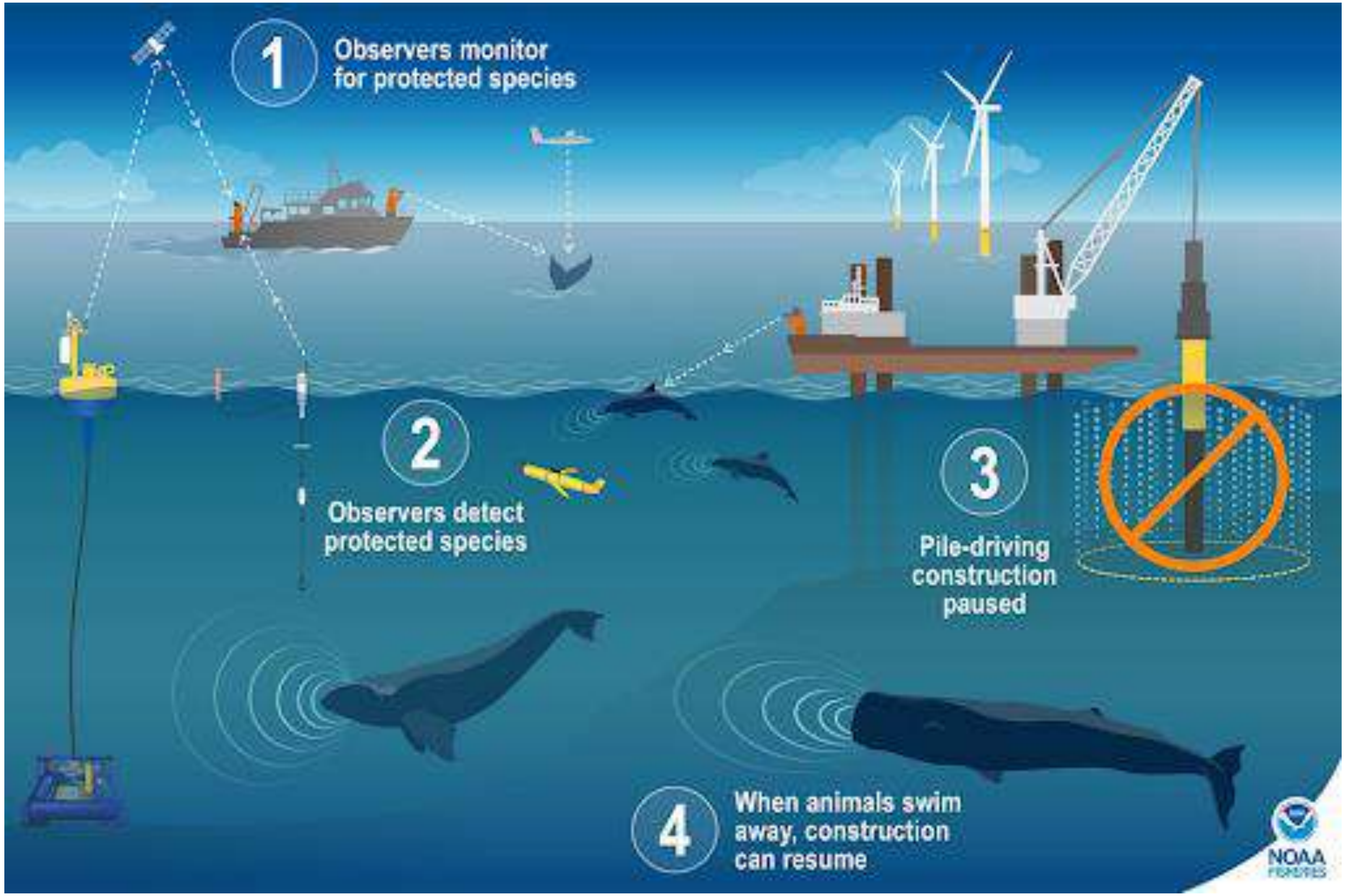


Fig. 12 Environmental & Noise Mitigation Technologies [19].

[19] http://www.anglersforoffshorewind.org/blog/noise-mitigation-systems-for-offshore-wind-monopile-installation

- For the seventh consecutive year, China added the most offshore wind capacity of any country.
- With 4 GW added to the grid in 2024, the country reached 41.8 GW by the end of 2024 [11].

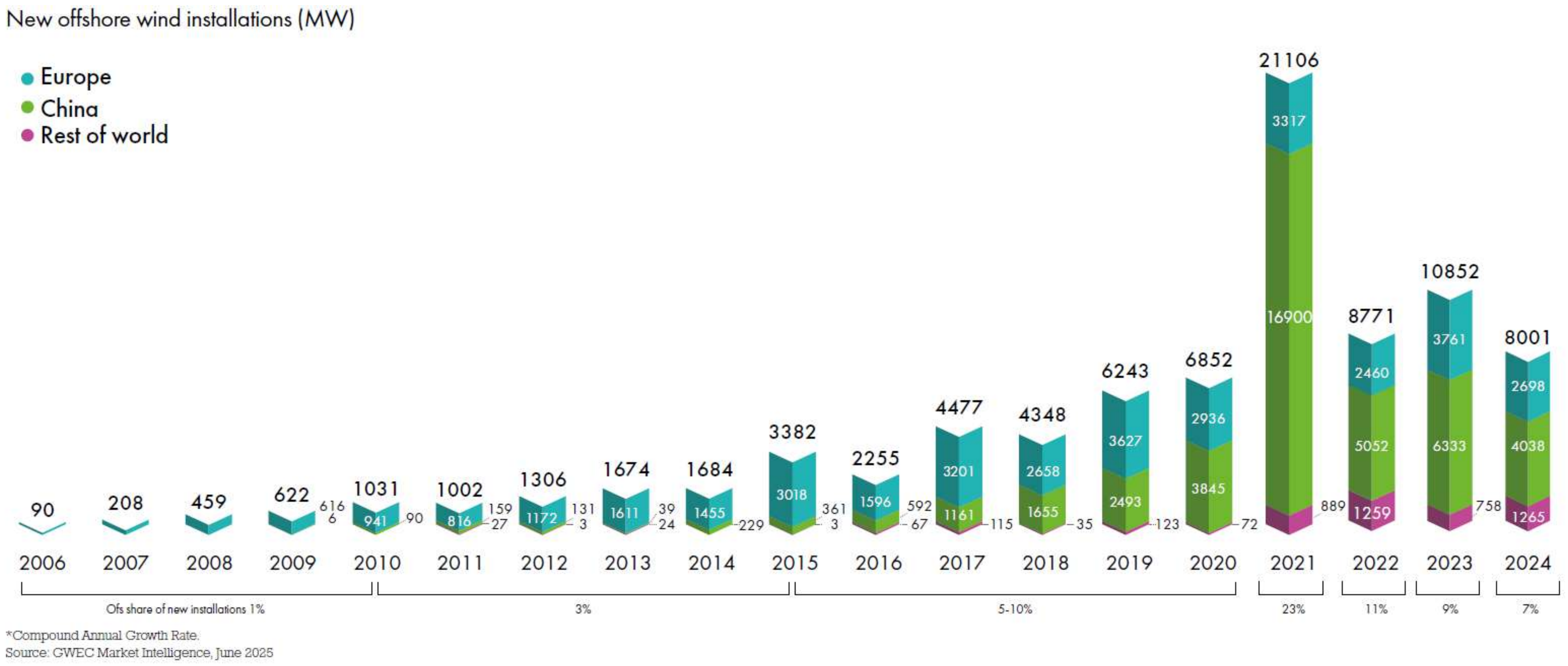


Fig. 13 Annual Installation.

Total Offshore Wind Installations by Market [11]

- The global offshore wind market has been growing by 10% on average each year over the past decade, with total installations of 83.2 GW representing 7.3% of the total wind capacity at the end of 2024.
- China is the absolute market leader for cumulative installations, accounting for half of the global market share.

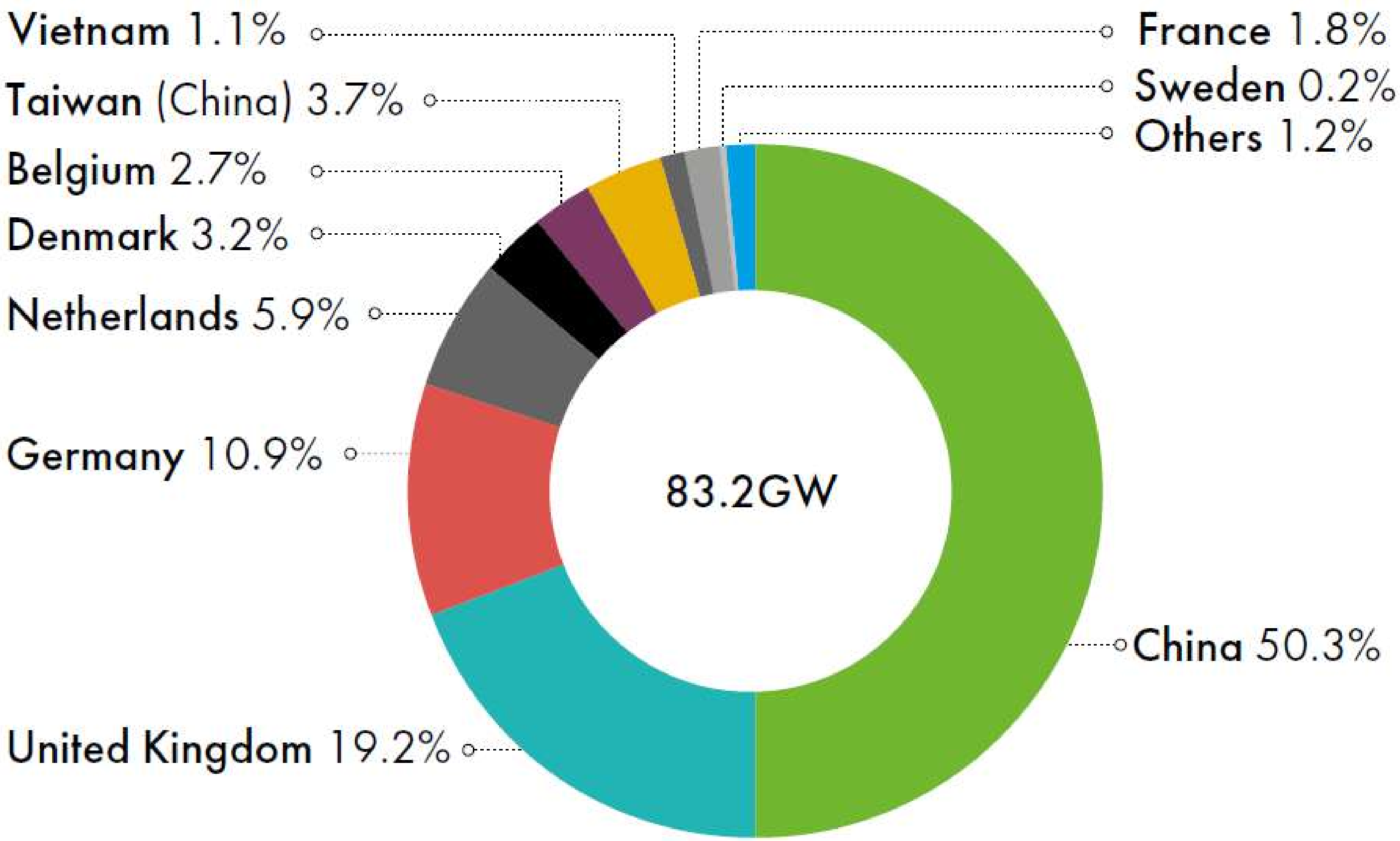


Fig. 14 Total offshore wind installations by market.

Total Offshore Wind Installations in the Asia Pacific Region (APAC) [11]

- APAC contributes 55.6% of total installed capacity.
- China is the absolute market leader in APAC as well as the world for cumulative installations, accounting for half of the global market share.
- South Asia region is not participating in the offshore installed capacity.

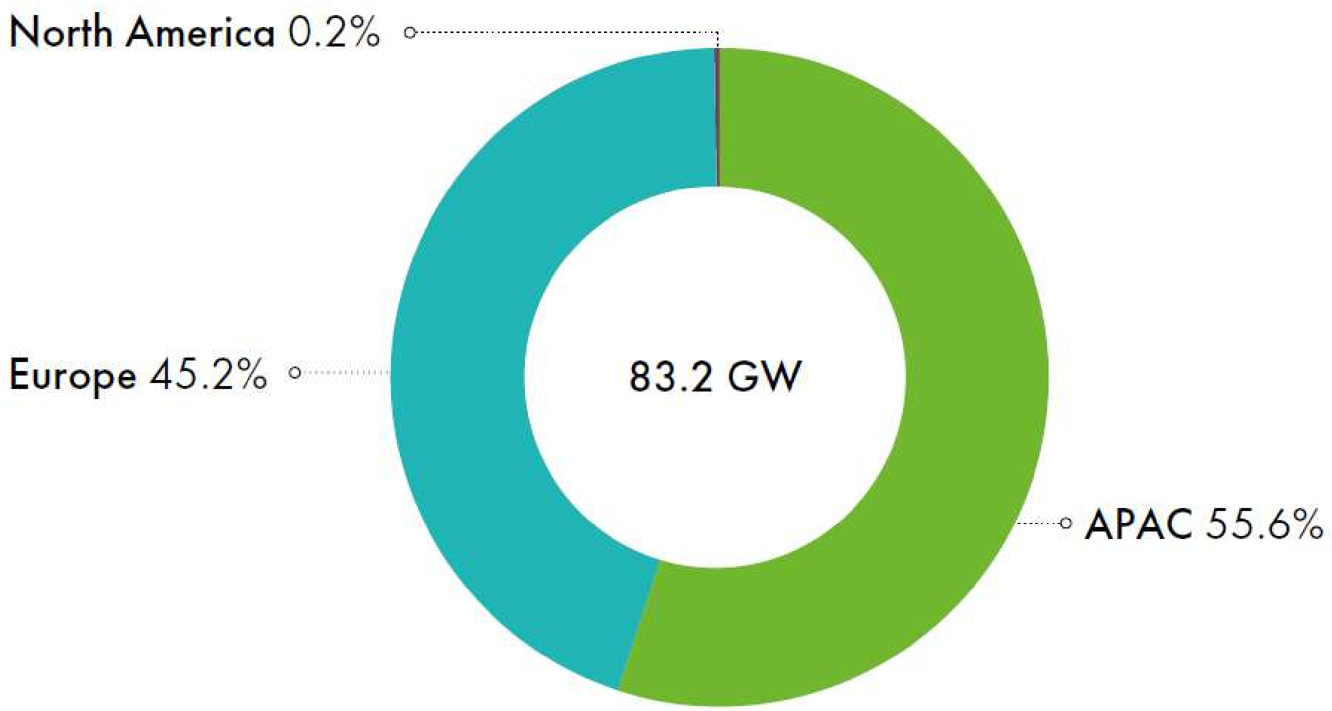


Fig. 15 Total offshore wind installations by region.

Global Offshore Market Outlook to 2034 [11]

- 350 GW of new offshore wind capacity to be added over the next decade (2025–2034), bringing total offshore wind capacity to 441 GW by the end of 2034.
- The Compound Annual Growth Rate (CAGR) is expected to remain the highest until 2030.

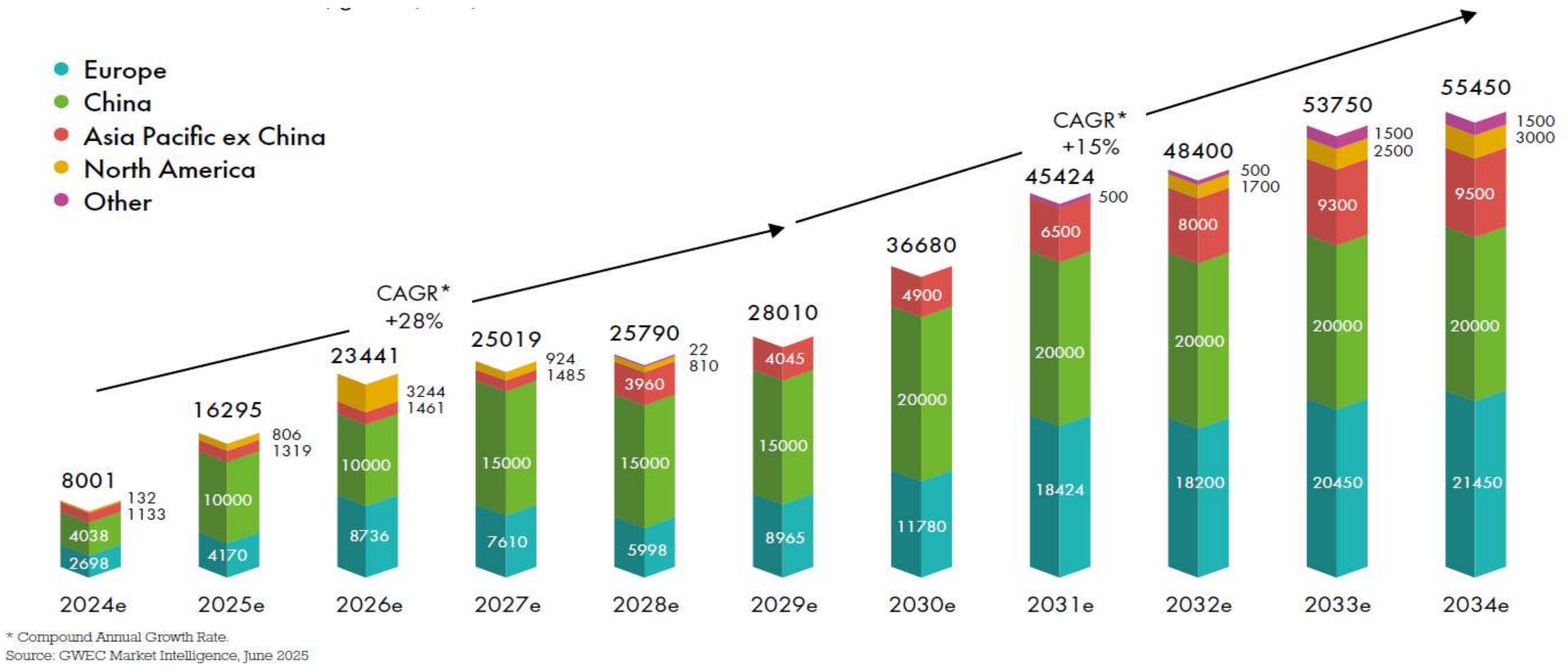


Fig. 16 New offshore wind installation, global (MW).

Offshore Wind Growth to 2034 in Asia Pacific (MW) [11]

- CAGR represents Compound Annual Growth Rate.
- In total, 215 GW of offshore wind capacity is predicted to be added in the next ten years, of which 36% will be in 2025–2029 and the remainder in 2030–2034.
- The top five markets in APAC for offshore wind additions over the next ten years will be China, Taiwan (China), South Korea, Japan and the Philippines.

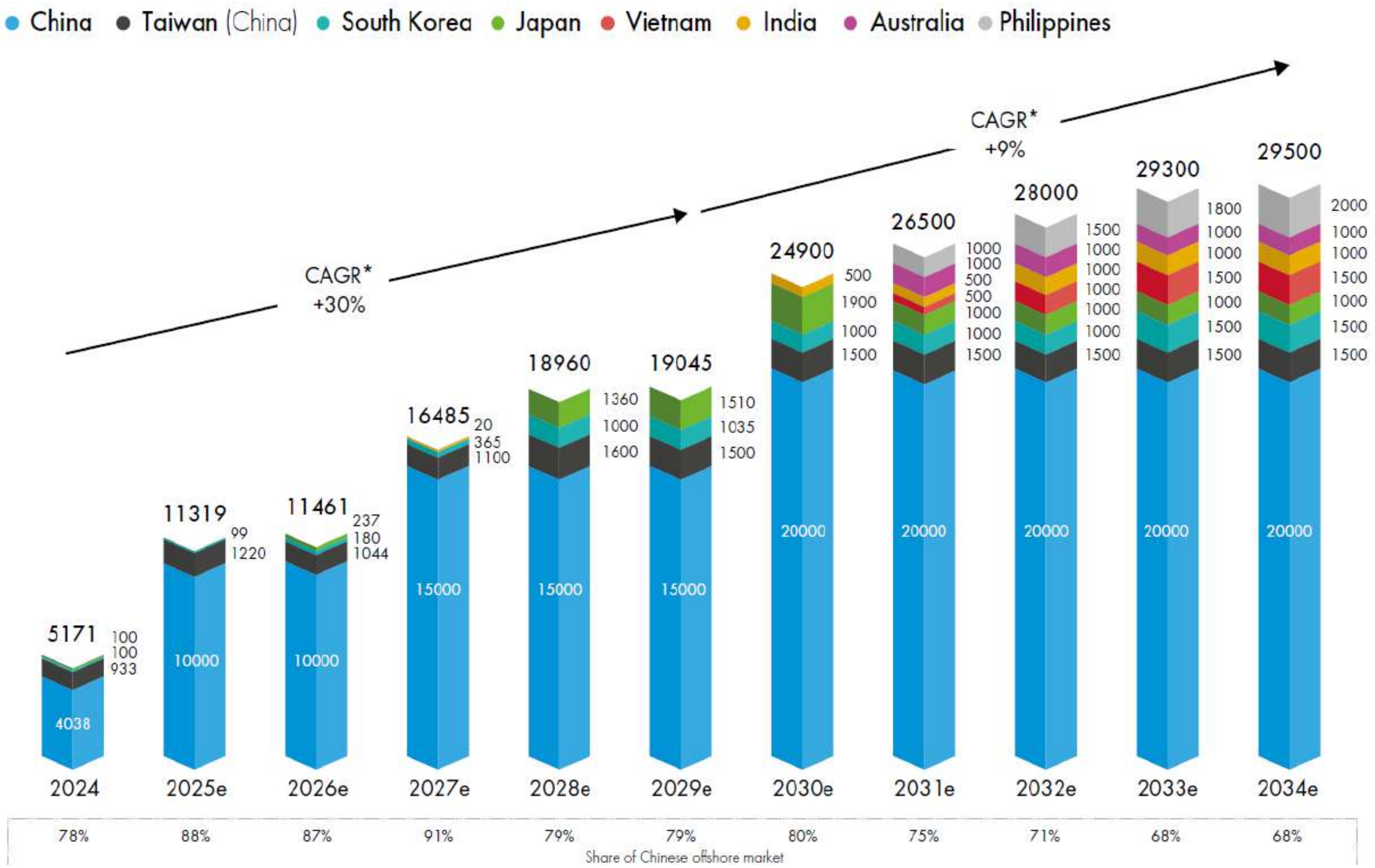


Fig. 17 New offshore wind installation, global (MW).

Total Offshore Wind Added Between 2025 and 2034 in APAC Region [11]

- Within the South Asia region, India is expected to contribute around 1.9% to offshore wind development.
- Other South Asian countries—such as Pakistan, Bangladesh, and Sri Lanka—do not have concrete offshore wind deployment plans or targets.

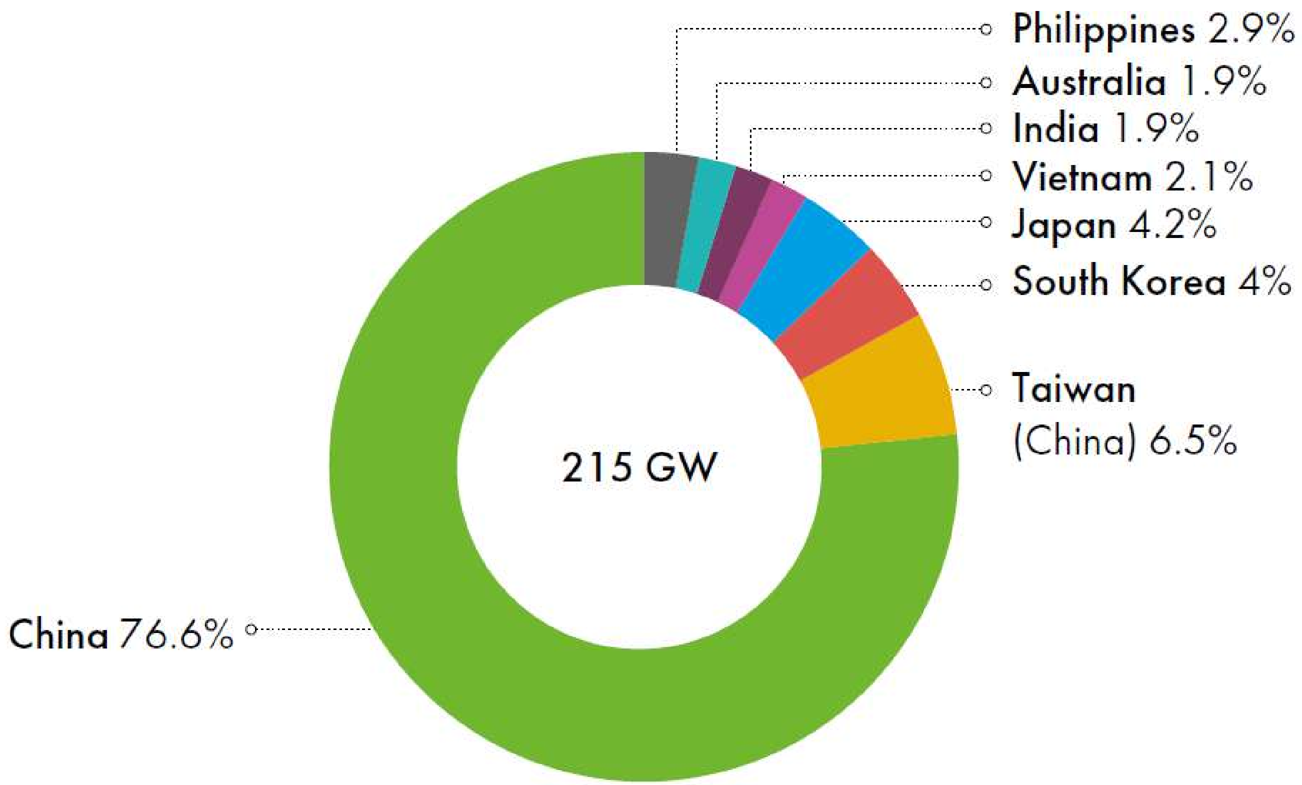


Fig. 18 New offshore wind installation, global (MW).

Capacity Utilization Factor (CUF): Offshore vs Onshore vs Solar

Table III: Comparative study of CUF [18]

Aspect	Offshore Wind	Onshore Wind	Solar PV
Capacity Utilization Factor (CUF)	**40–60%** (best among RES)	**25–35%**	**15–25%**
Resource Quality	Very strong & consistent wind, low turbulence	Moderate wind, higher turbulence	Highly dependent on sunlight availability, weather, seasons
Variability	**Lowest variability** due to stable offshore wind patterns	Medium variability	**Highest variability** (day-night cycle + weather)
Predictability	High	Medium	Low–Medium
Land Requirement	No land needed	Large land area required	Very large land area required
Energy Density	**Highest** energy output per unit capacity	Medium	Lowest
Impact on Grid	More stable generation → easier forecasting	Medium	Needs storage or advanced grid support
Best Use Case	Large-scale reliable power for coastal regions	Land-based wind corridors	Distributed or utility-scale solar in sunny regions

Tariff of Offshore, Onshore, and Solar Energy

Table IV: Comparison table with typical (or recent average) tariffs / LCOE (Levelized Cost of Energy for offshore wind, onshore wind, and solar [18][20].

Technology	**Approximate Tariff / LCOE**
Offshore Wind	₹ 6.0 – 6.5 / kWh
Onshore Wind	₹ 2.8 – 3.4 / kWh
Solar PV (Utility Scale)	₹ 2.5 – 2.9 / kWh
Wind–Solar Hybrid	₹ 3.1 – 3.7 / kWh

[20] https://energy.economictimes.indiatimes.com/news/renewable/significant-tariff-differences-across-indias-energy-segments-amid-new-offshore-wind-funding-crisil/111309881

Policy Recommendations [11]

Enact clear deployment mandates and roadmaps:
Legislate offshore wind targets with milestones for both auction volumes and permitting timelines, giving the industry long-term visibility on pipeline size and schedule.

Establish single-window or lead agency systems:
Centralise all permit reviews (environmental, safety, grid, maritime) under one authority to establish maximum review durations and reduce inter-agency.

Embed “overriding public interest” in national law:
Mirror Germany’s implementation of the EU principle, ensuring courts value renewables expansion as highly as environmental standards, which helps reduce legal appeals and accelerates approvals.

Designate permit-ready zones in advance:
Publish spatial plans with predetermined site areas and grid connection points to give developers confidence that sites are technically and legally cleared for auction.

Facilitate early stakeholder engagement:
Require preapplication consultations with fishing communities, coastal communities and environmental groups to identify and mitigate conflicts before formal review, minimising late-stage objections.

Overview Of Offshore Grid Delivery Models [11]

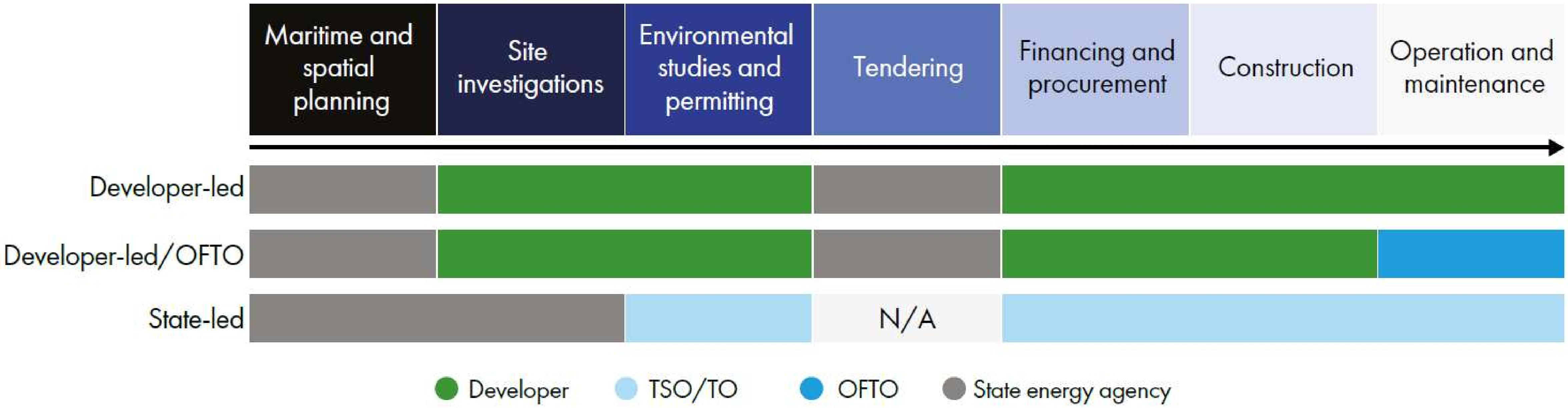


Fig. 19 Overview of offshore grid delivery models.

- The figure illustrates how responsibilities for offshore grid delivery are distributed across different phases of development, from early spatial planning to long-term operation and maintenance.
- This reinforces how delivery models influence the pace, coordination and efficiency of offshore wind expansion.

Wind Energy Conversion System [21]

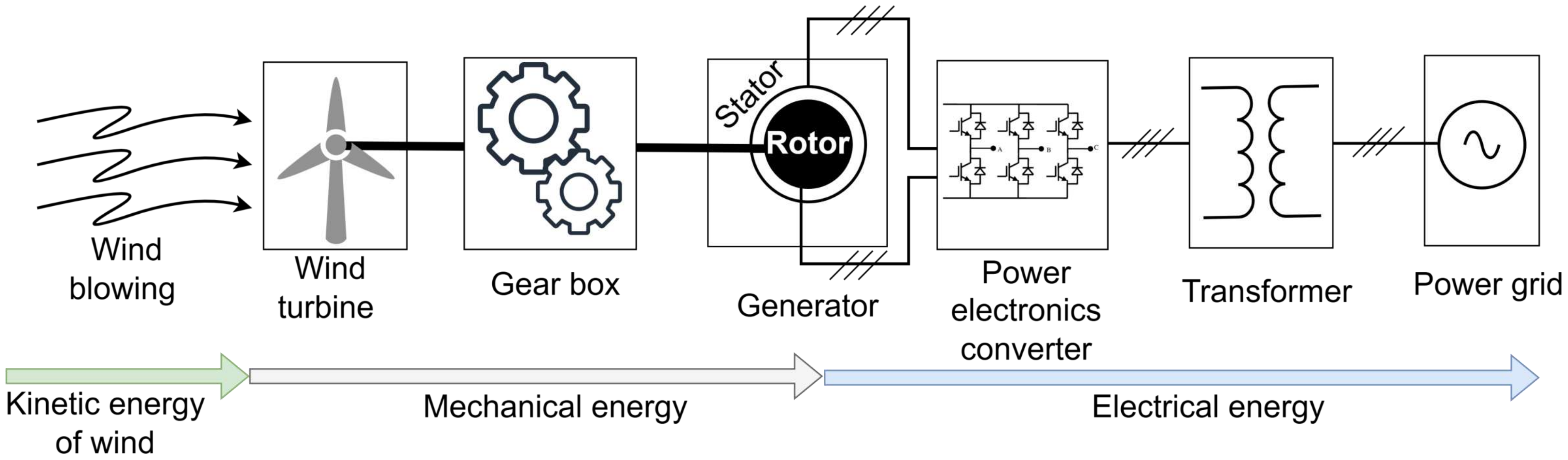


Fig. 20 Basic structure of wind energy conversion system.

[21] Xu, D., Blaabjerg, F., Chen, W., & Zhu, N. (2018). *Advanced control of doubly fed induction generator for wind power systems*. John Wiley & Sons.

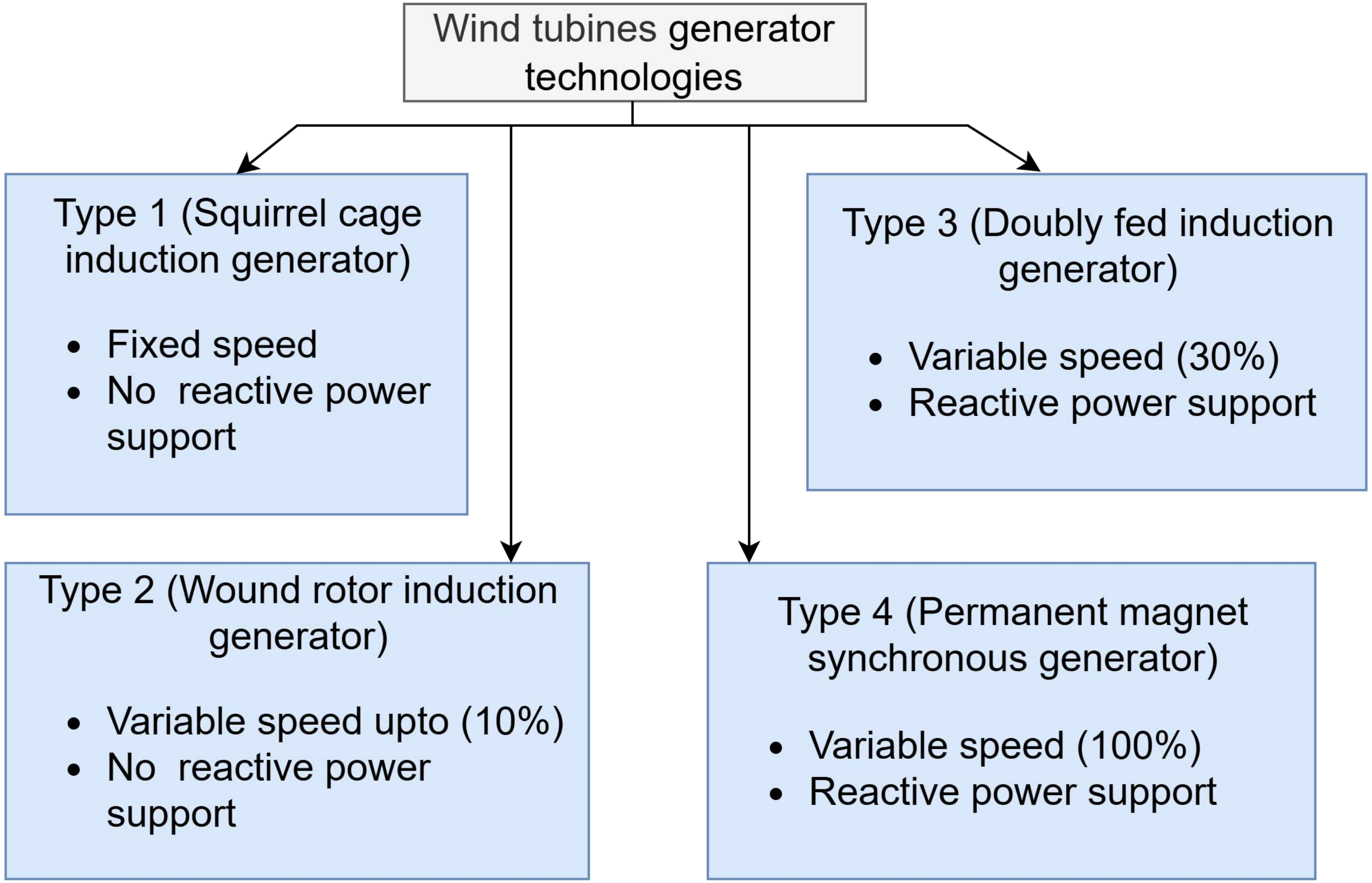


Fig. 21 Types of wind turbine technology.

Types of Wind Turbine Technologies

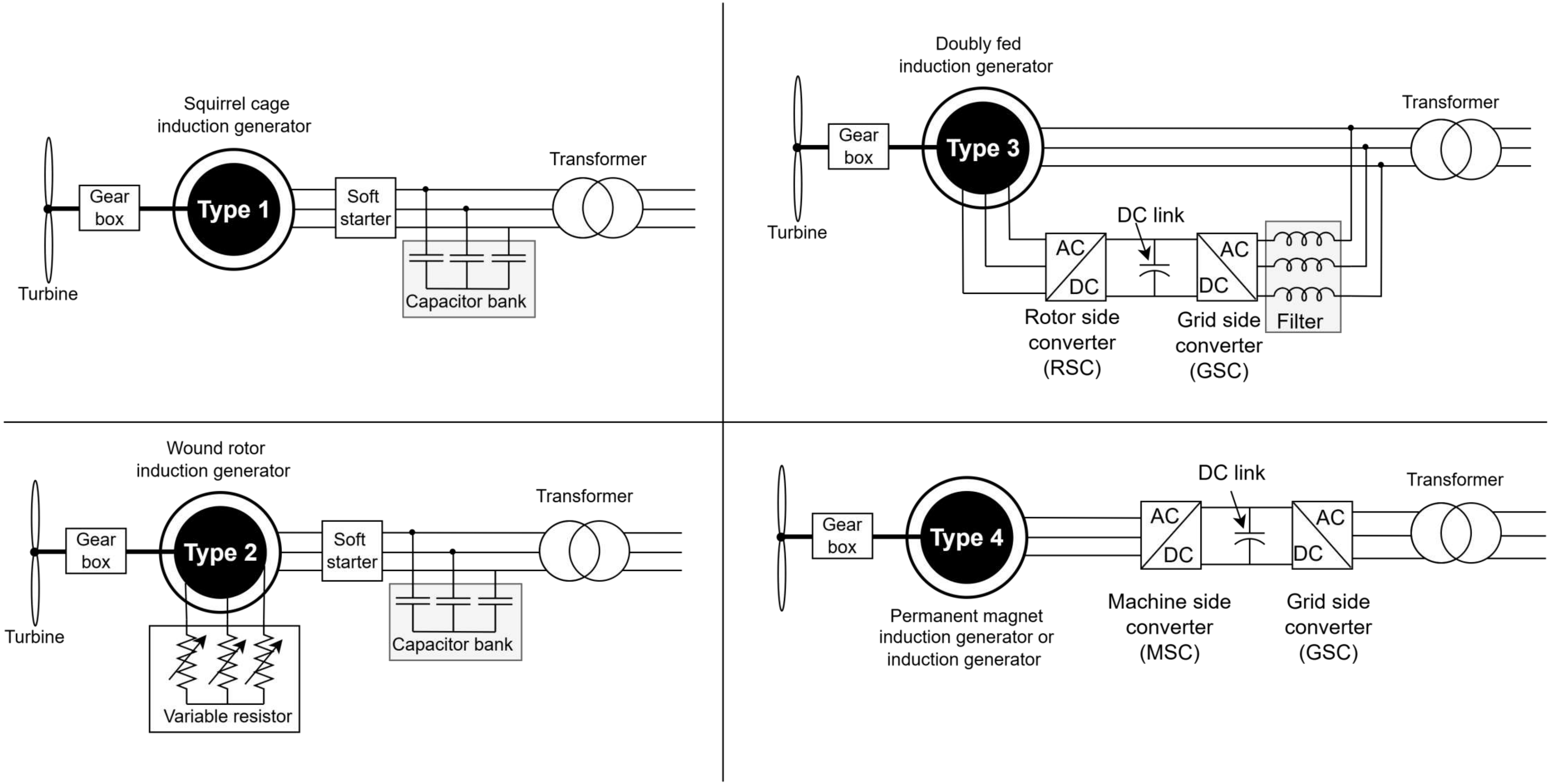


Fig. 22 Types of wind turbine technology.

Schematic of Doubly Fed Induction Generator

- The Rotor Side Converter (RSC) extracts energy from the wind and enables maximum power tracking.
- Grid Side Converter (GSC) regulates the DC-link voltage and provides reactive power support.
- Switches SW1 and SW2 facilitate the synchronization of the DFIG with the grid.

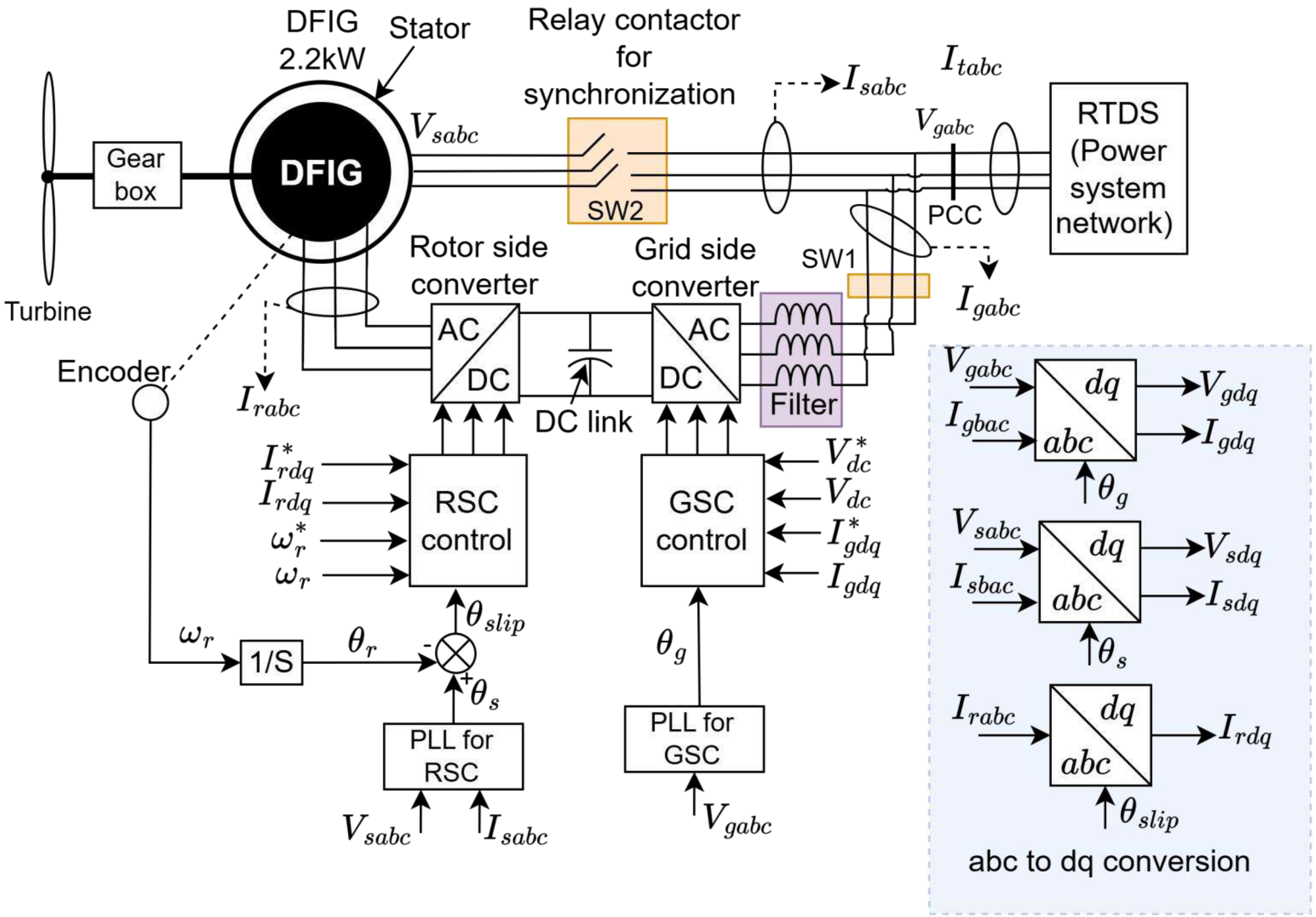


Fig. 23 Schematic of DFIG.

Control of Doubly Fed Induction Generator

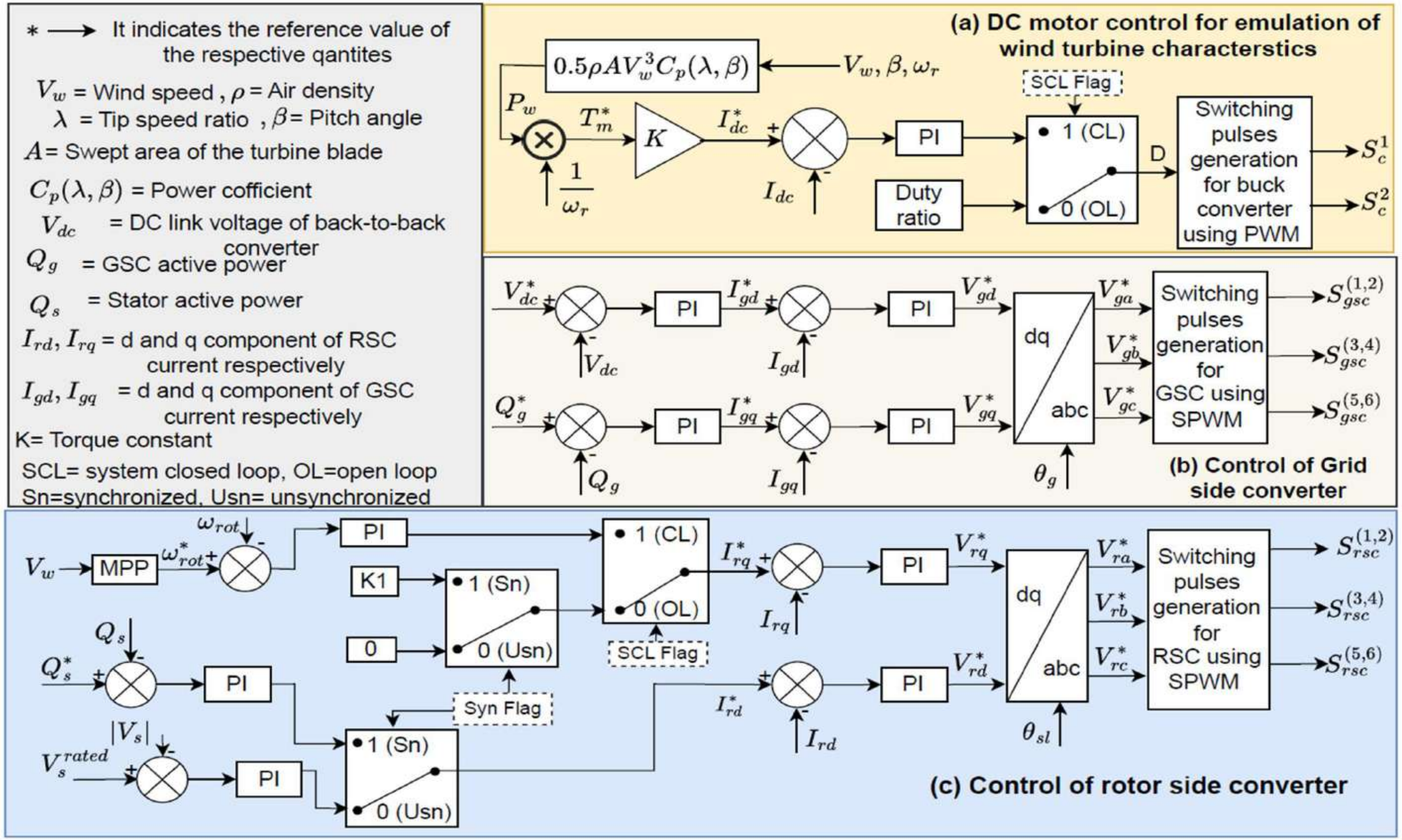


Fig. 24 Control of DFIG.

Hardware Setup of Doubly Fed Induction Generator

Table V: Parameters of the DFIG for a simulation study

Power	2.5MW
Voltage	690V
Frequency	50/60Hz
Rotor/stator turns ratio	2.6377

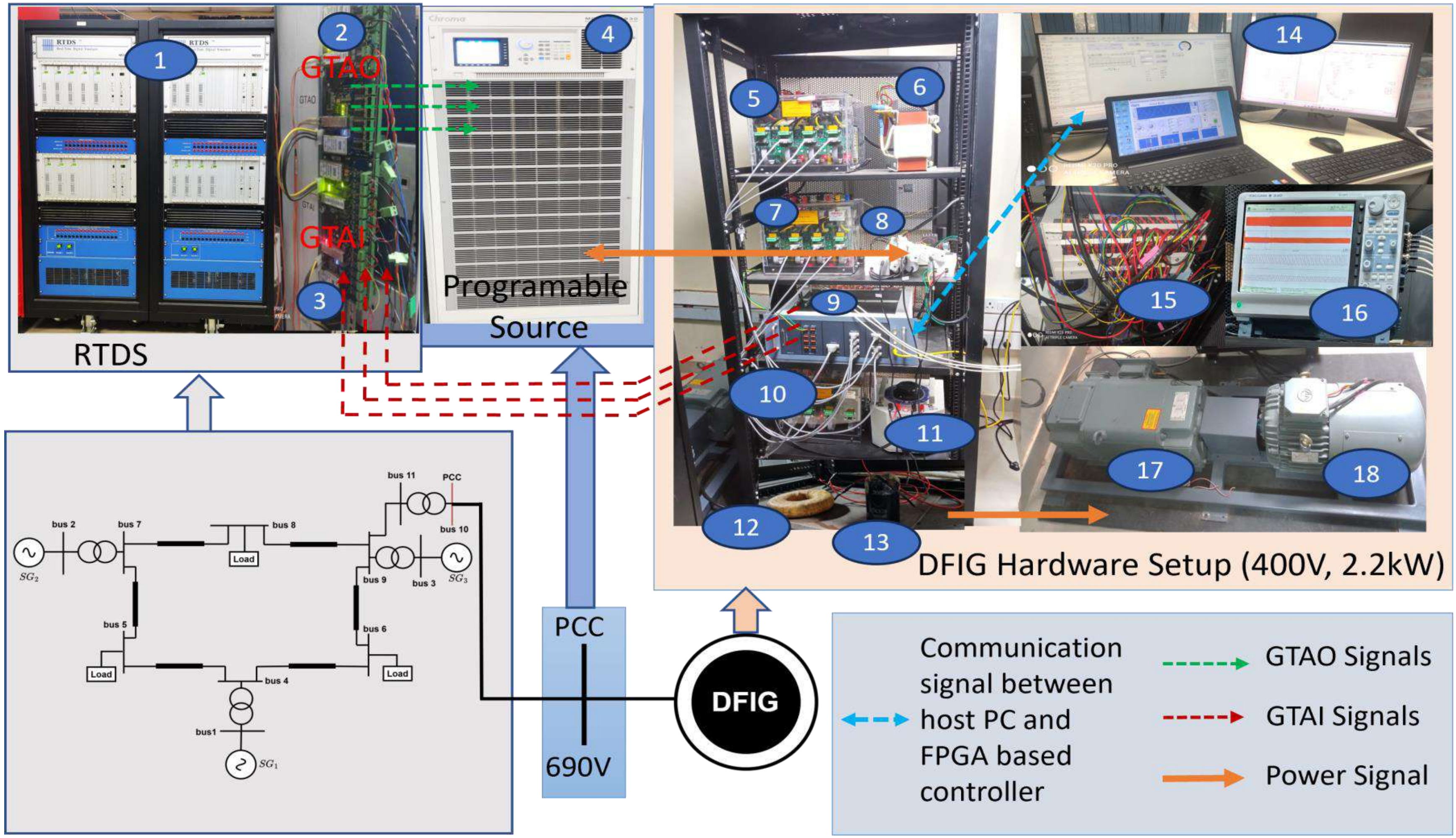


Fig. 25 (a) HIL setup: (1) RTDS, (2) GTAO ports, (3) GTAI ports, (4) programmable source, (5) GSC, (6) L filter, (7) RSC, (8) current prob, (9) FPGA based controller, (10) buck converter, (11) auto transformer, (12) inductor for buck converter, (13) capacitor for buck converter, (14) host PC, (15) voltage and current sensors, (16) DSO, (17) DC motor, (18) DFIG.

Stepwise Startup and Synchronization Process of DFIG:

- Step 1: acceleration of the rotor.
- Step 2: activation of the grid-side converter.
- Step 3: activation of the rotor side converter.
- Step 4: synchronization.

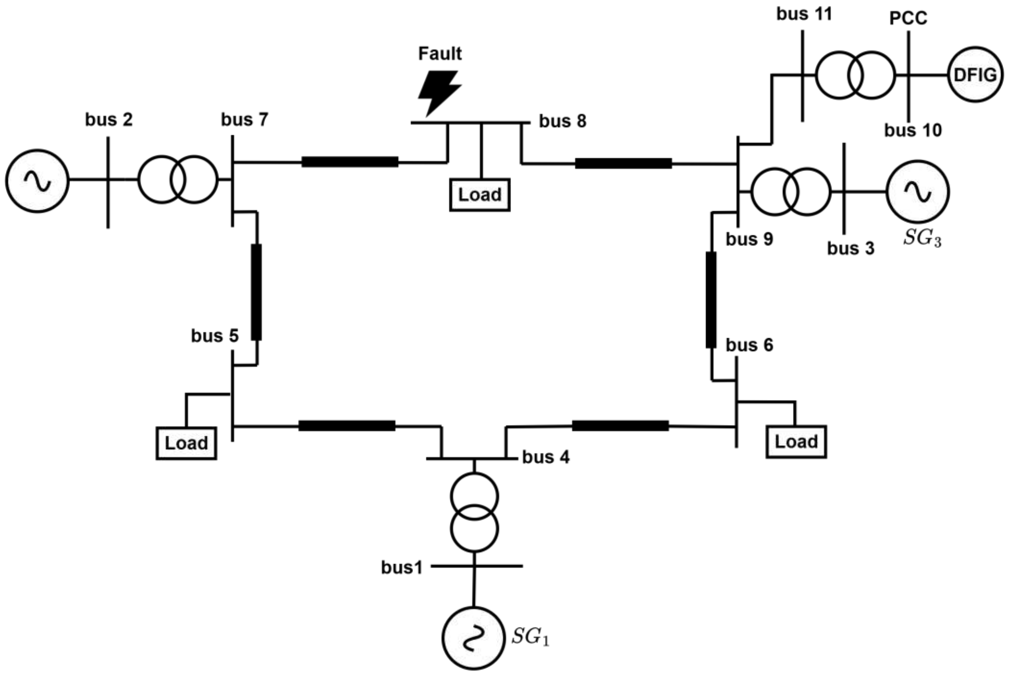


Fig. 26 Test system.

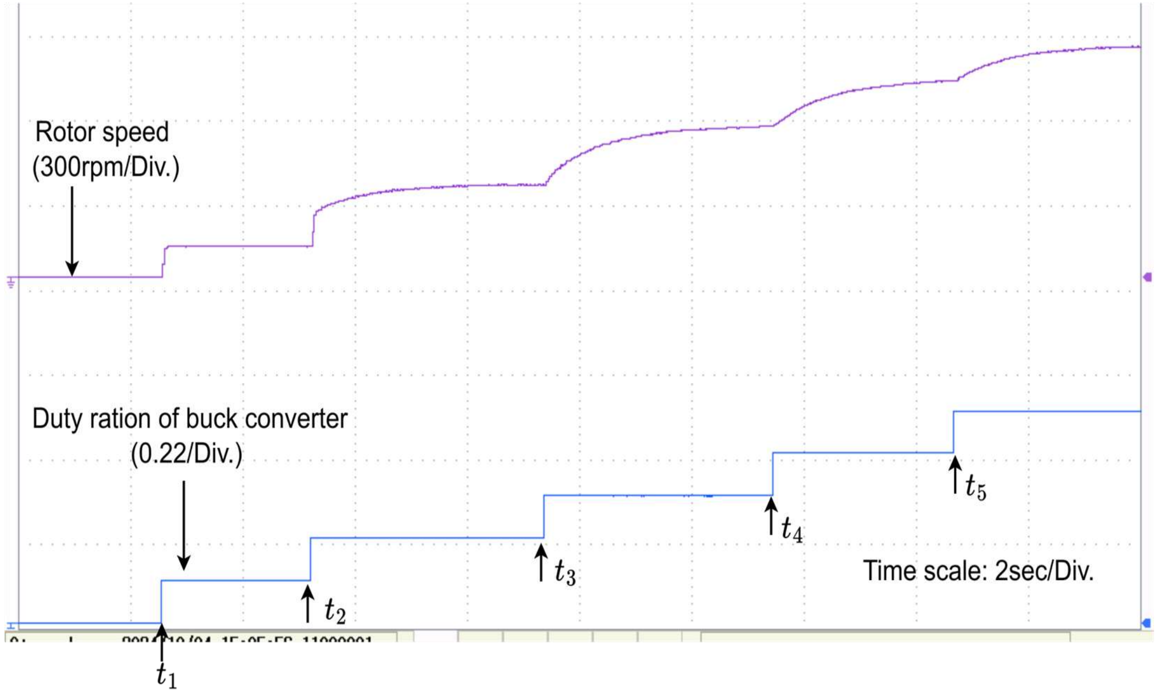


Fig. 27 Step 1: acceleration of a separately excited DC motor, which is used as a wind emulator.

Startup and Synchronization Process of DFIG using PHIL Setup

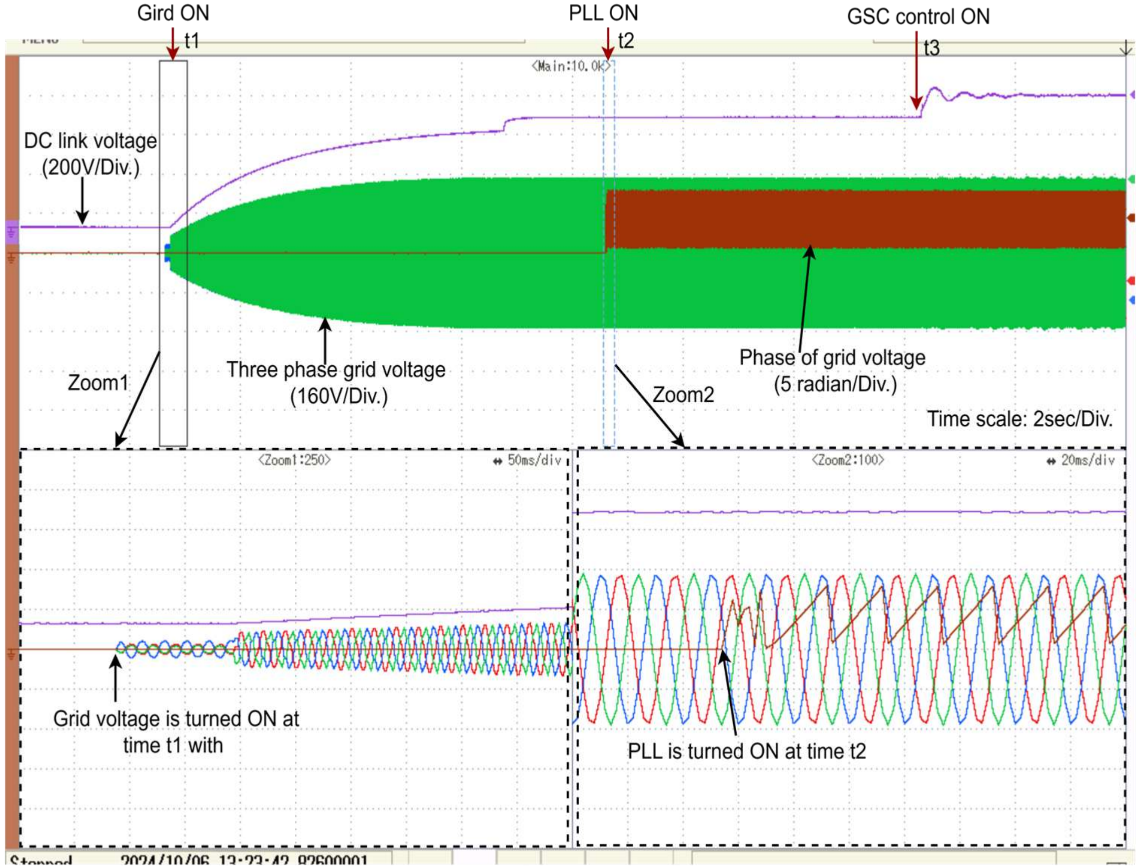


Fig. 28 Step 2: activation of the GSC to control and maintain the DC link to the rated value.

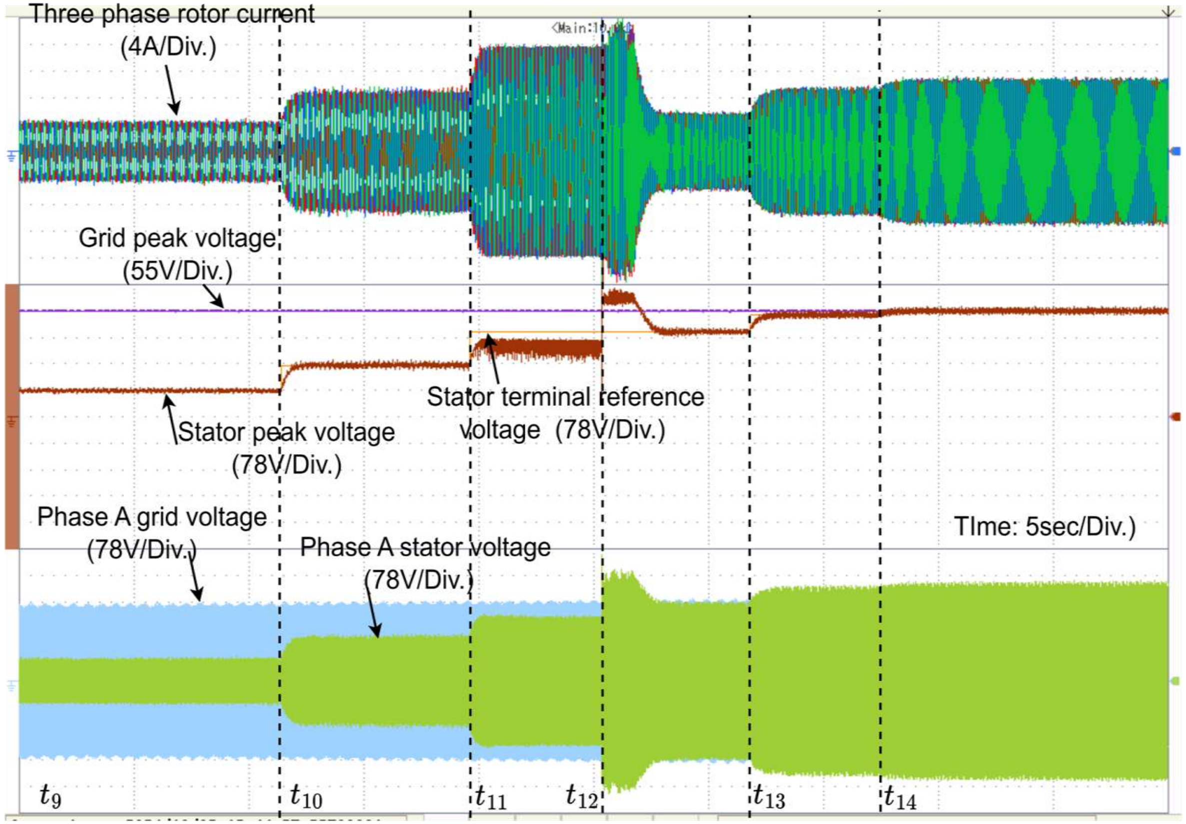


Fig. 29 Step 3: developing the stator terminal voltage using the RSC control.

Startup and Synchronization Process of DFIG using PHIL Setup

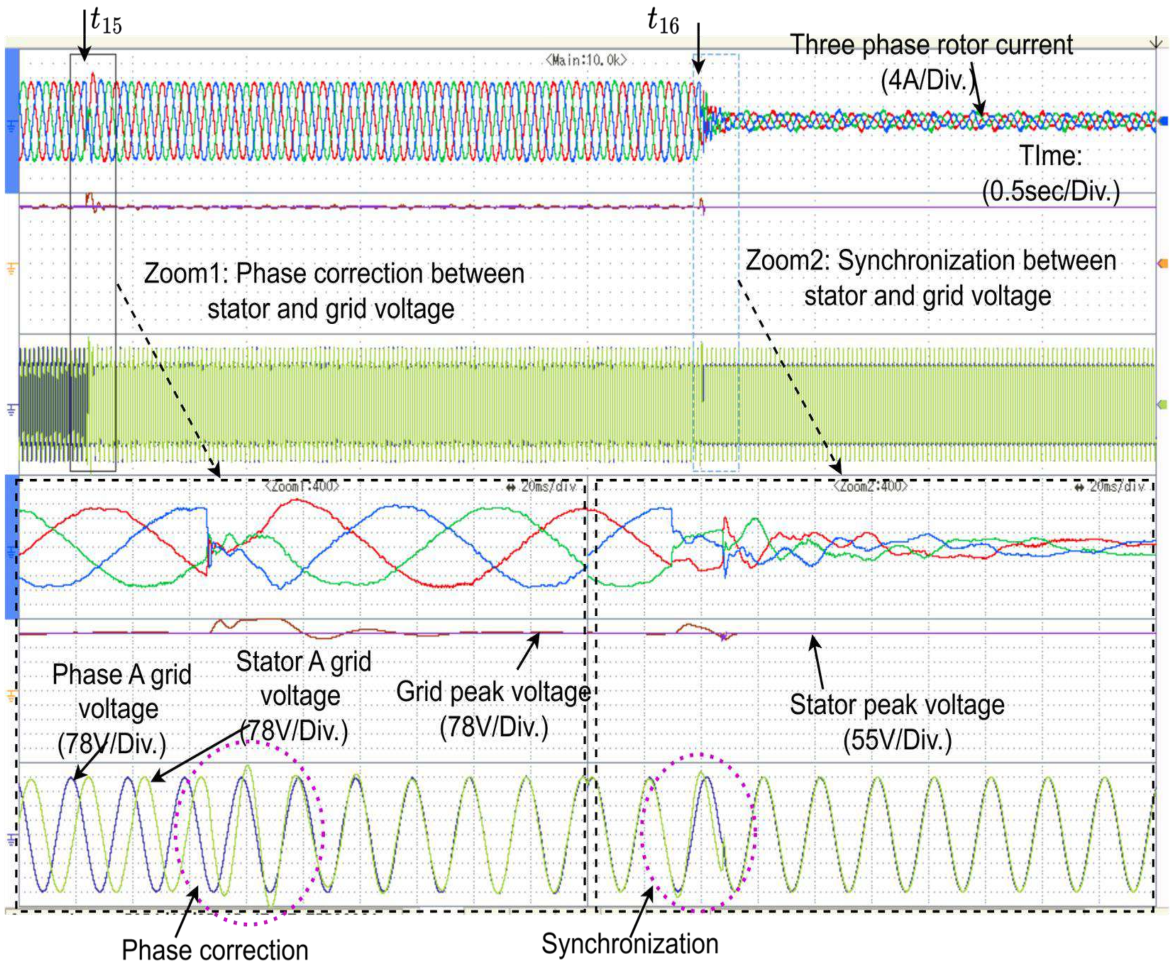


Fig. 30 Step 4: synchronization process.

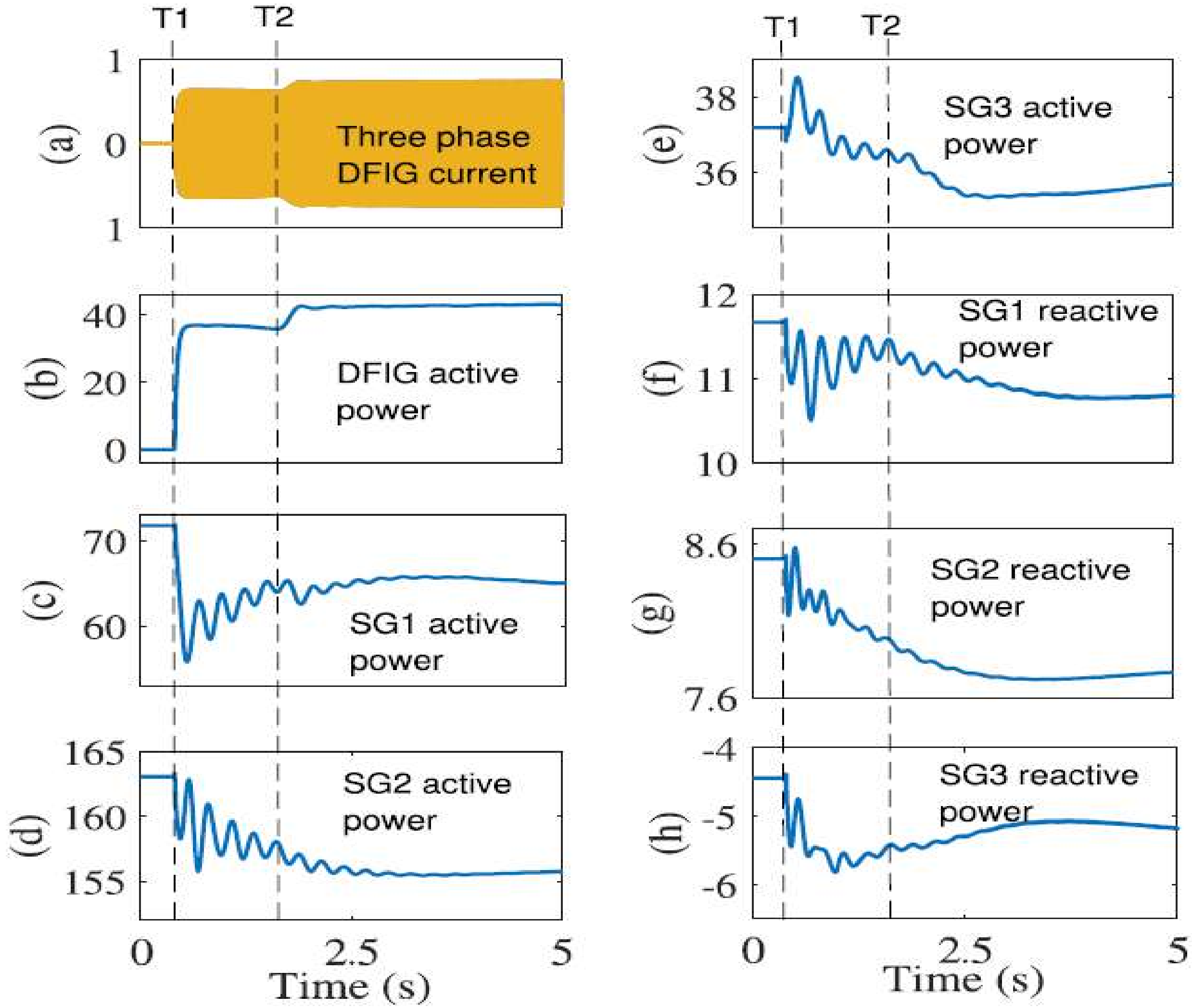


Fig. 31 Operating variables of DFIG and synchronous generators under a change of the operating point of DFIG.

PHIL Experimentation on Fault Ride Through Behaviour of Doubly Fed Induction Generator-Based Wind System in the Presence of Fault Current Limiter

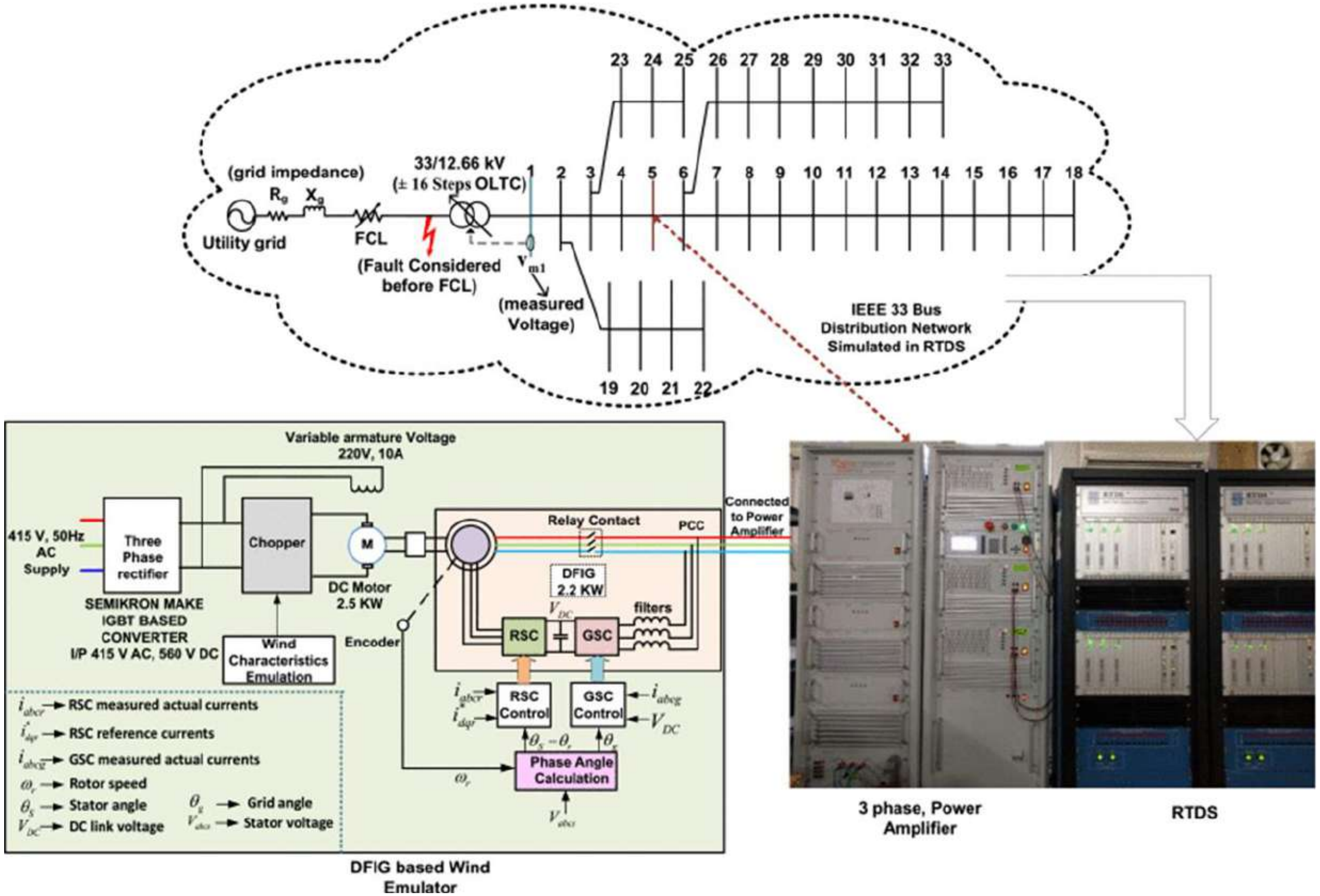


Fig. 32 System under study—DFIG-based wind emulator connected to the IEEE 33 bus distribution network, simulated in real time through a power amplifier.

PHIL Experimentation on Fault Ride Through Behaviour of Doubly Fed Induction Generator-Based Wind System in the Presence of Fault Current Limiter

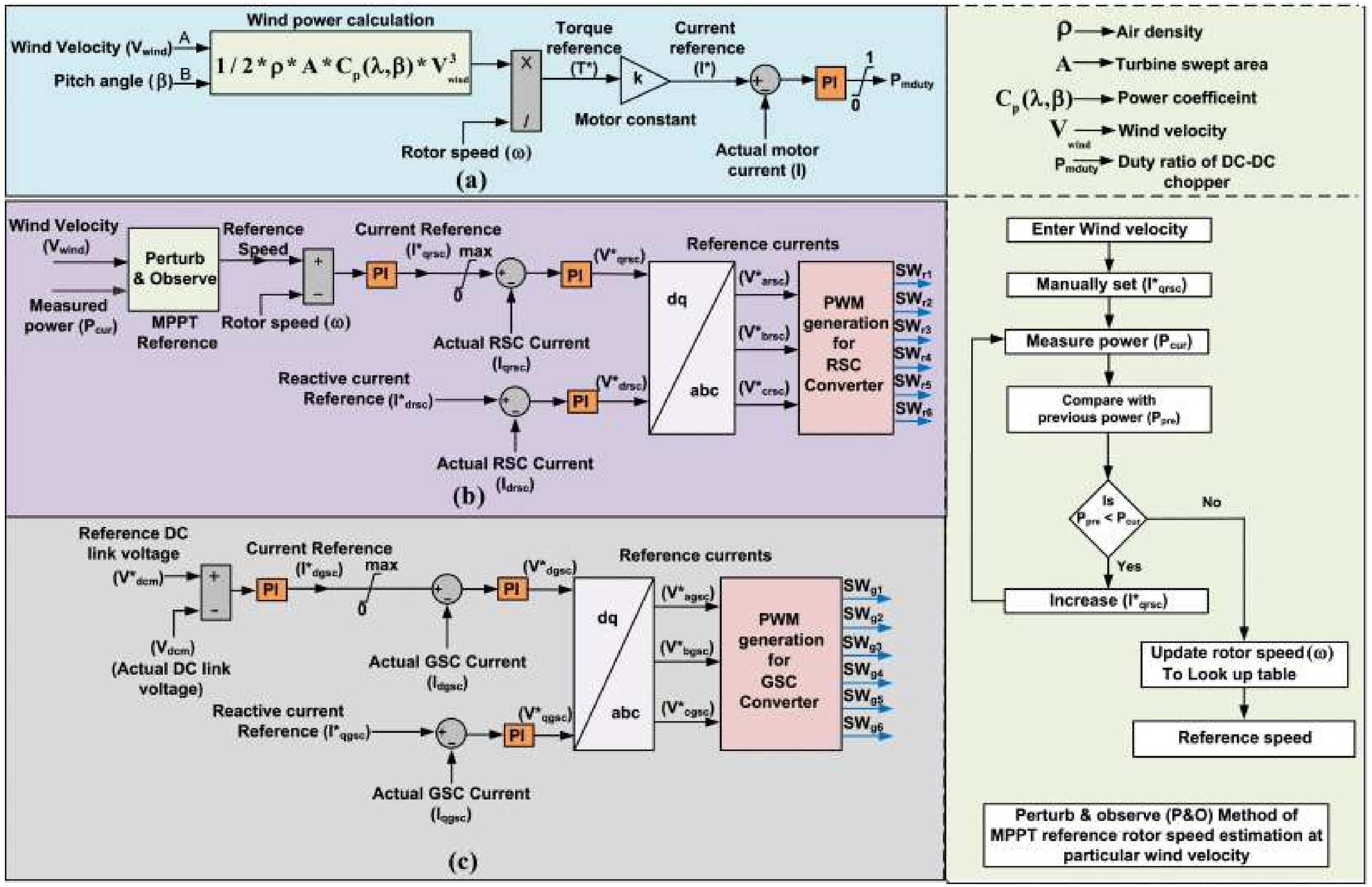


Fig 33. DFIG control strategy. (a) DC motor control to emulate wind characteristics by controlling duty ratio of dc–dc chopper. (b) RSC control to track MPPT and to control machine power factor. (c) GSC control to regulate the dc link voltage and to inject the reactive power.

PHIL Experimentation Results

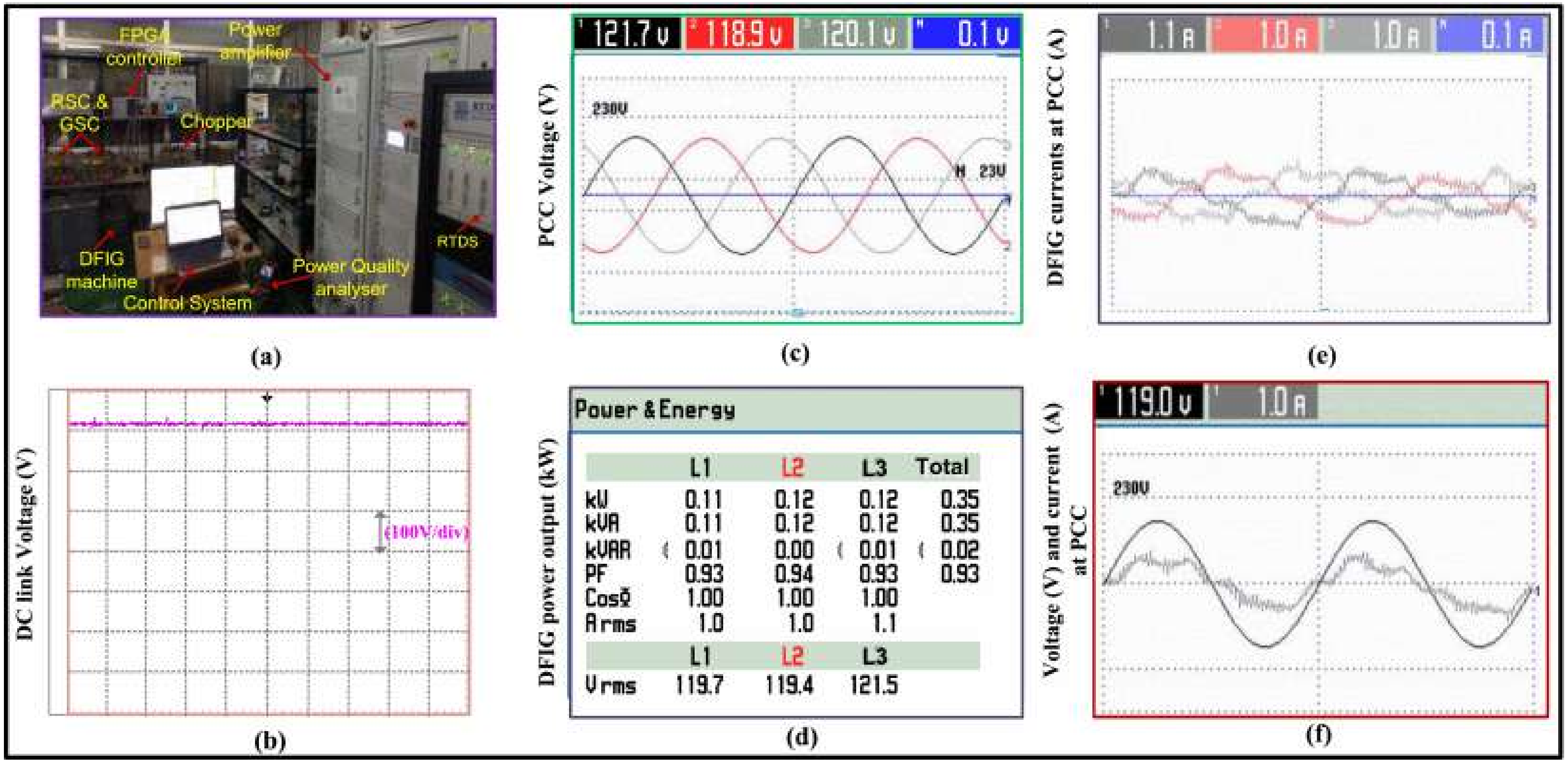
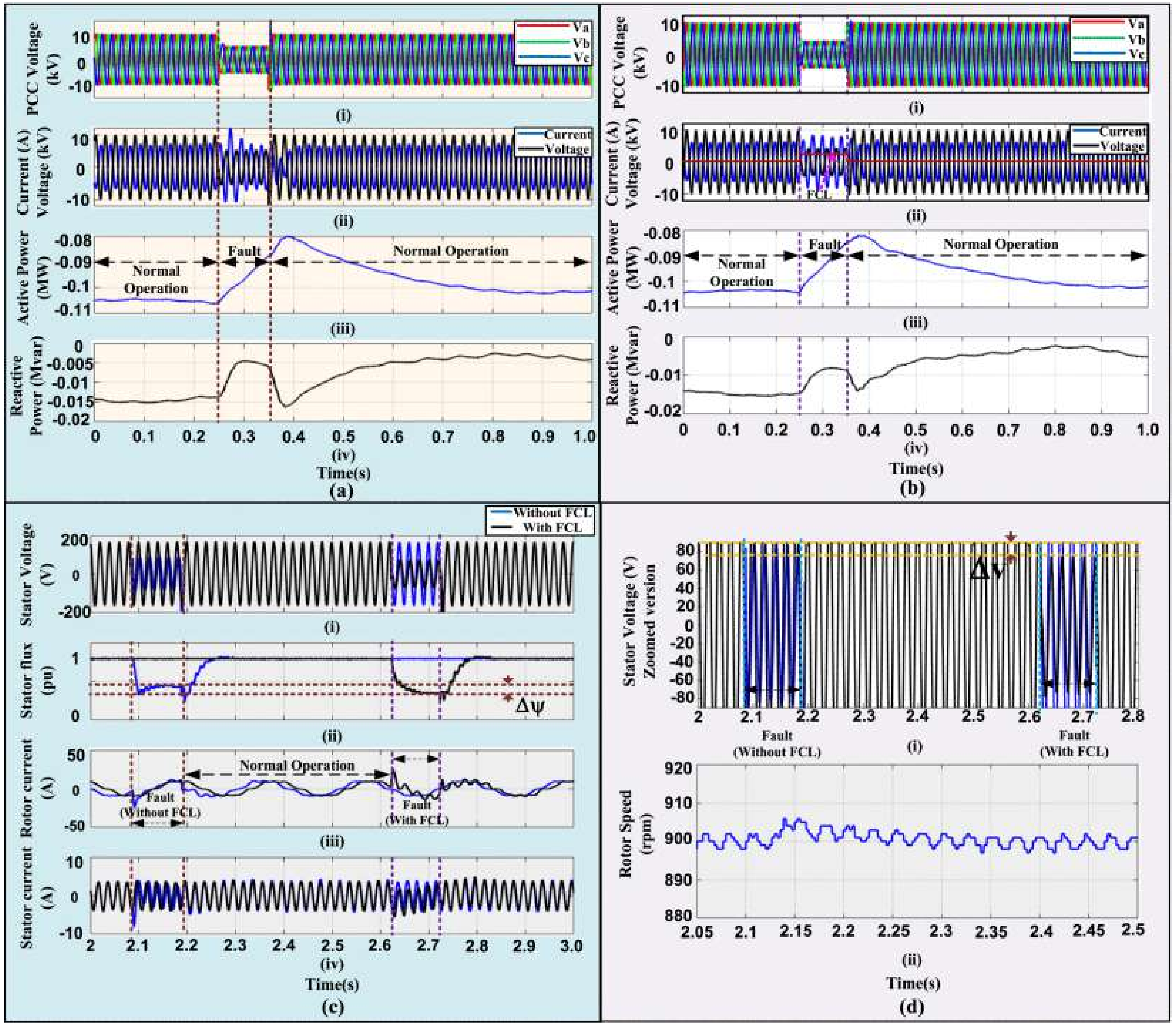


Fig. 34 Experimental results. (a) Setup. (b) DC link voltage. (c) PCC voltage (PAS voltage). (d) DFIG power output. (e) DFIG current. (f) PCC voltage and current.

Fig. 35 PHIL experimental results. (a) RTDS results without using FCL: (i) PCC Voltage at bus 5. (ii) Voltage and current of phase A. (iii) Active power injected at bus 5. (iv) Reactive power injected at bus 5. (b) RTDS results with FCL: (i) PCC Voltage at bus 5. (ii) Voltage and current of phase A, action of FCL (0–2 Ω). (iii) Active power injected at bus 5. (iv) Reactive power injected at bus 5. (c) DFIG results with and without FCL: (i) Stator voltage. (ii) Stator flux. (iii) Rotor current. (iv) Stator current. (d) DFIG results with and without FCL continued: (i) Stator voltage zoomed version. (ii) Speed of rotor.



Operation of the Fault Current Limiter

Fig. 36 (a) Intermediate solution: (i) action of unidirectional FCL when fault occurs after FCL. (ii) Action of unidirectional FCL when fault occurs before FCL. (b) PHIL experimentation setup of the proposed arrangement to improve FRT of DFIG wind system when fault occurs before FCL. (c) Pictorial representation of the system under study with the proposed arrangement. (i) During normal operation. (ii) During fault.

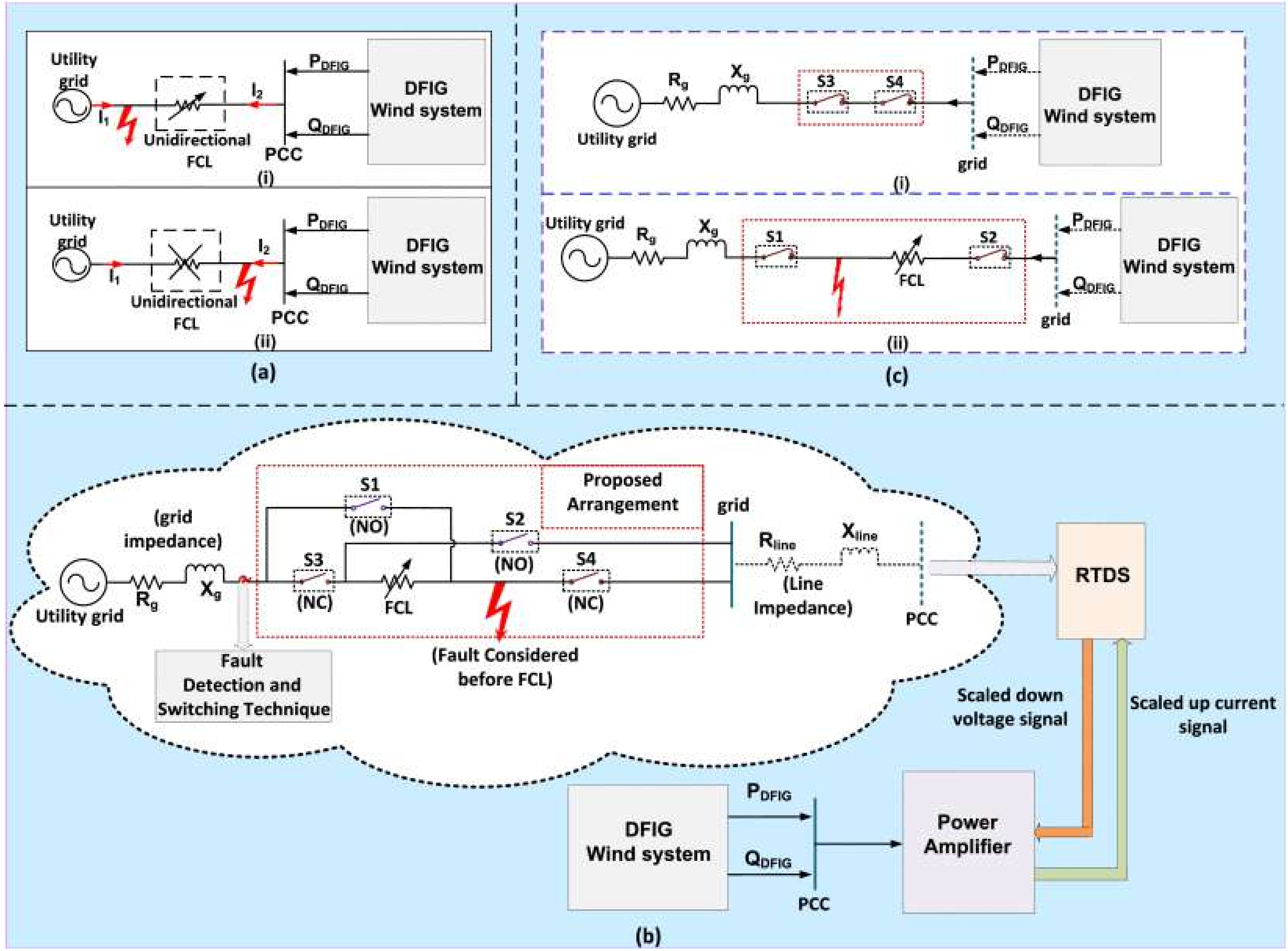
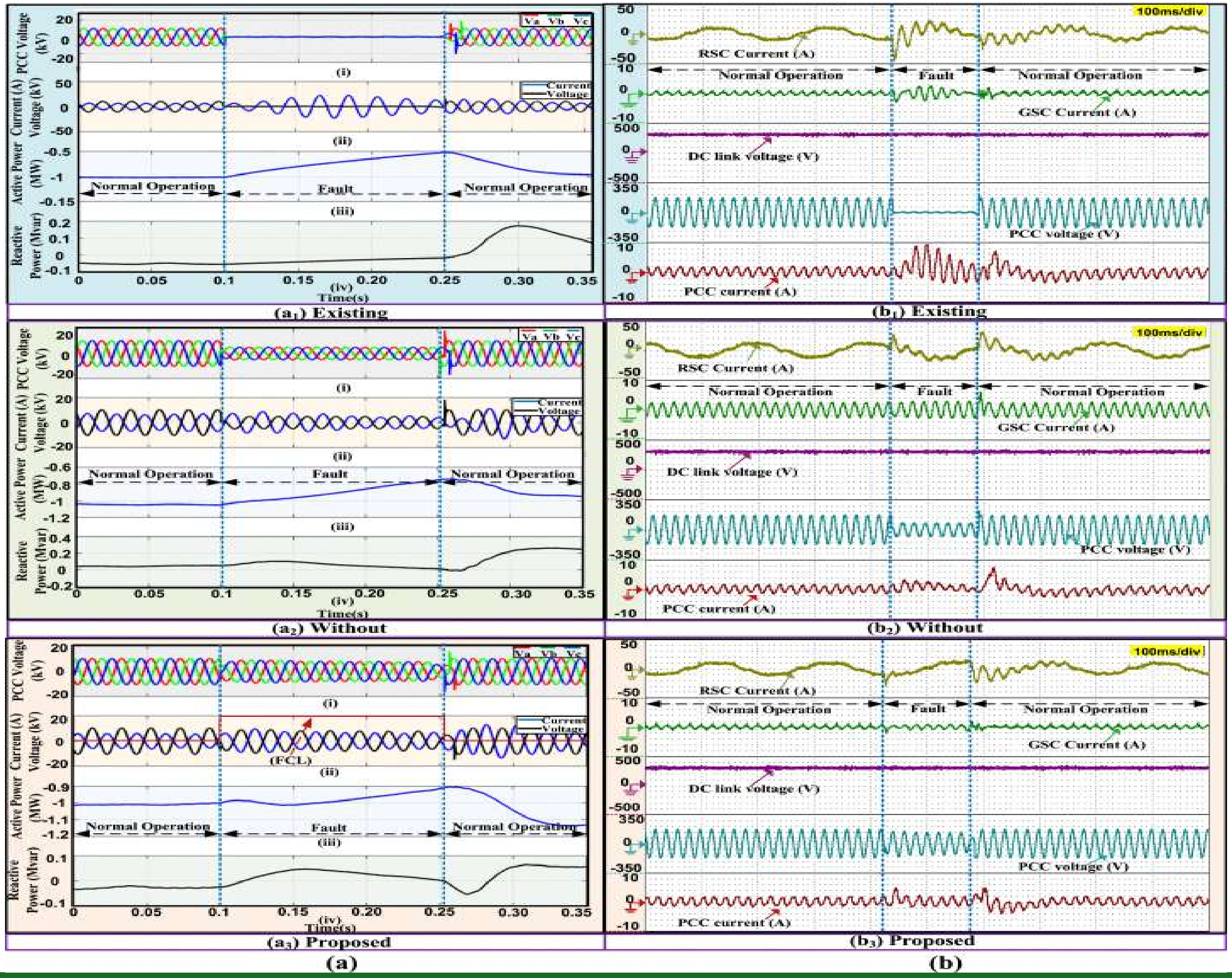
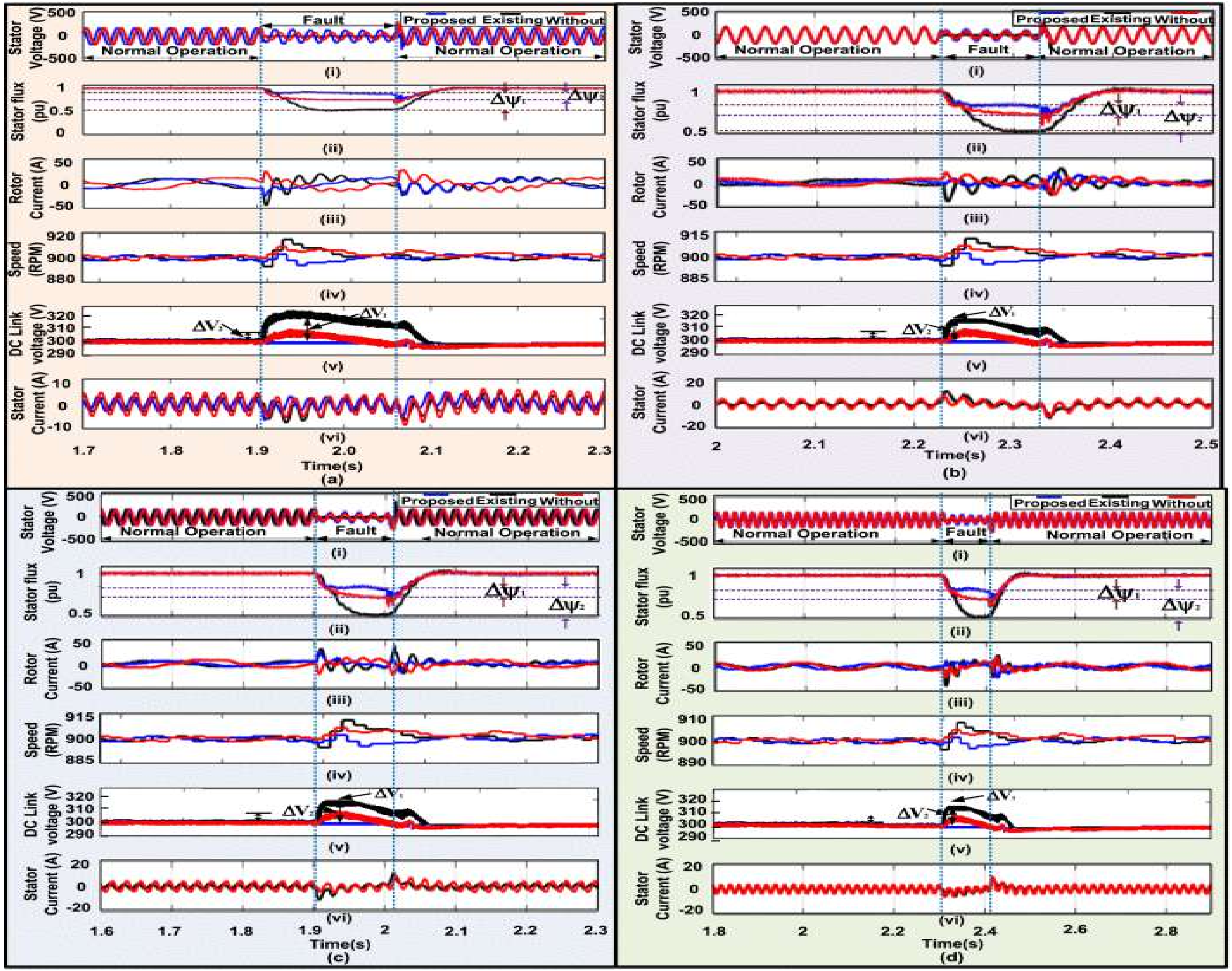


Fig. 37 PHIL experimentation results for fault taking place before the FCL. (a) At RTDS platform-Bus 5 results (PCC Voltage, current injected, active power, reactive power measured at PCC). (b) At FPGA platform-DFIG results (RSC current, GSC current, dc-link voltage, PCC voltage and current measured at power amplifier). (a1,b1) Existing arrangement of the FCL. (a2, b2) Without FCL. (a3, b3) Proposed arrangement of the FCL.



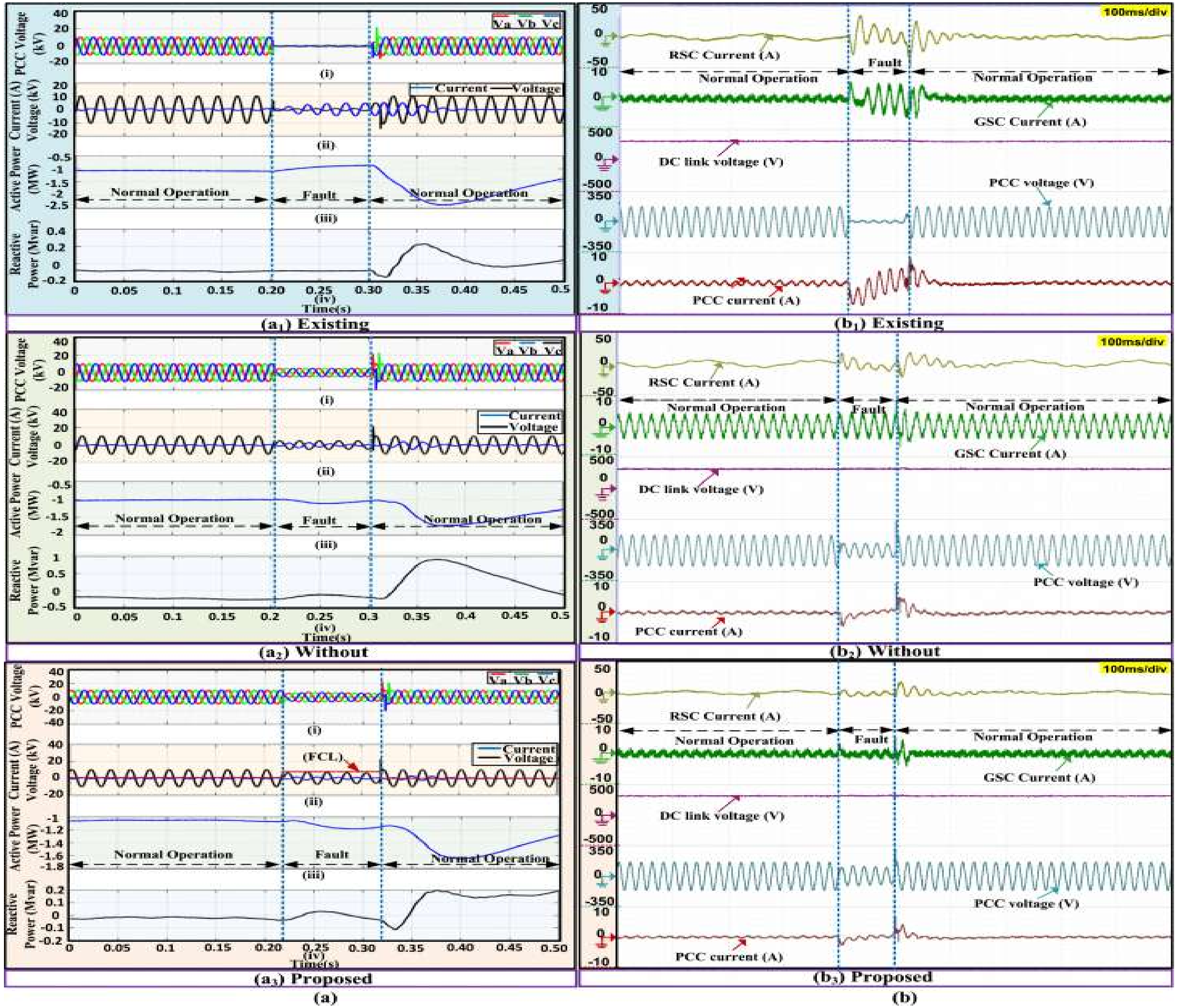
PHIL Experimentation Results

Fig. 38 DFIG response to fault taking place before FCL during subsynchronous operation. (a) With 20 Ω resistance, different fault perception instants. (b) First Instant. (c) Second Instant. (d) Third Instant all with 6 Ω resistance. (i) Stator voltage. (ii) Stator flux. (iii) Rotor current. (iv) Speed. (v) DC link voltage. (vi) Stator current.



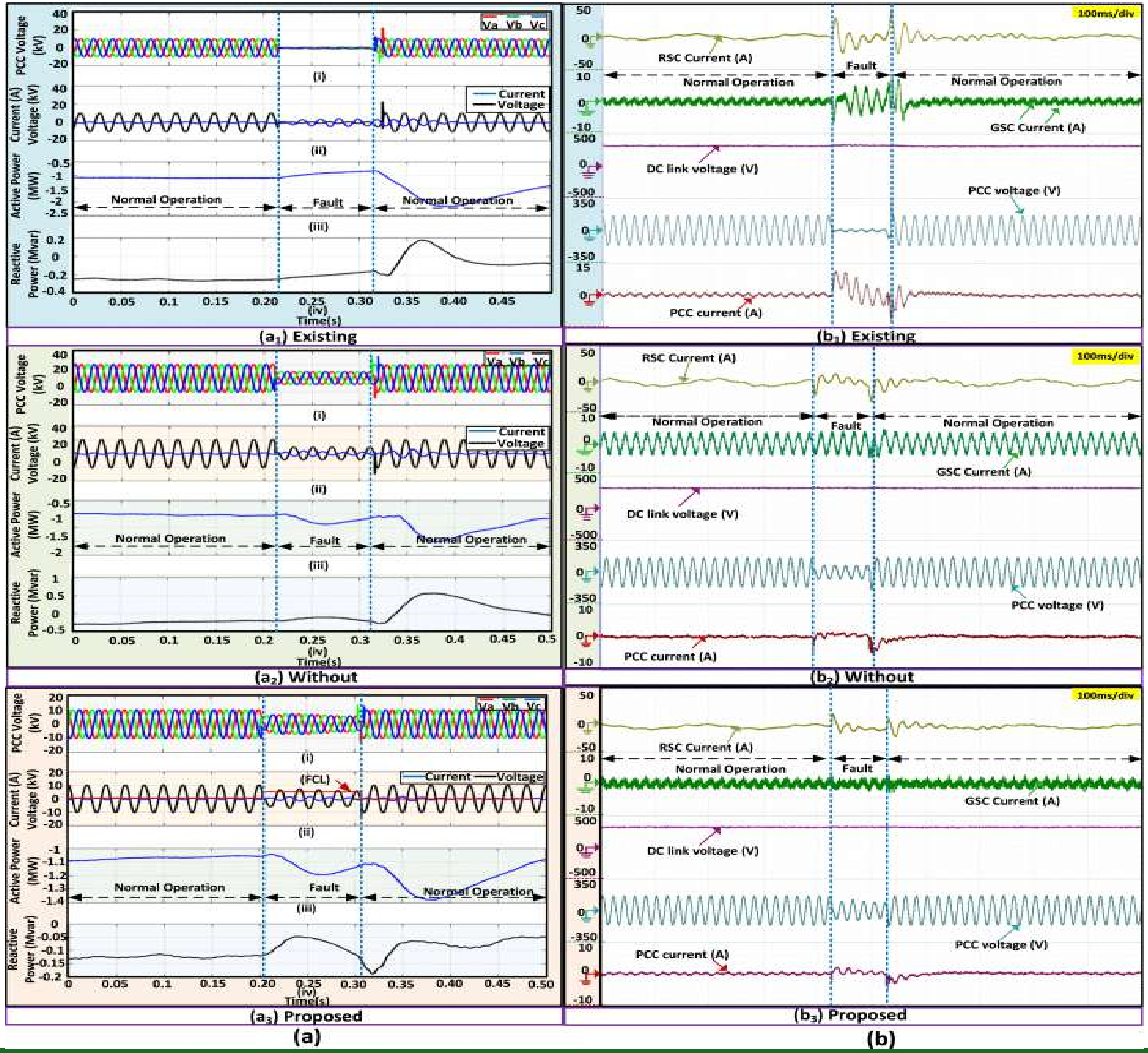
PHIL Experimentation Results

Fig .39 PHIL experimentation results for fault taking place before the FCL at first fault instant during subsynchronous operation. (a) At RTDS platform-Bus 5 results (PCC Voltage, current injected, active power, reactive power measured at PCC). (b) At FPGA platform-DFIG results (RSC current, GSC current, dc link voltage, PCC voltage and current measured at power amplifier). (a1, b1) Existing arrangement of the FCL. (a2, b2) Without FCL. (a3, b3) Proposed arrangement of the FCL.



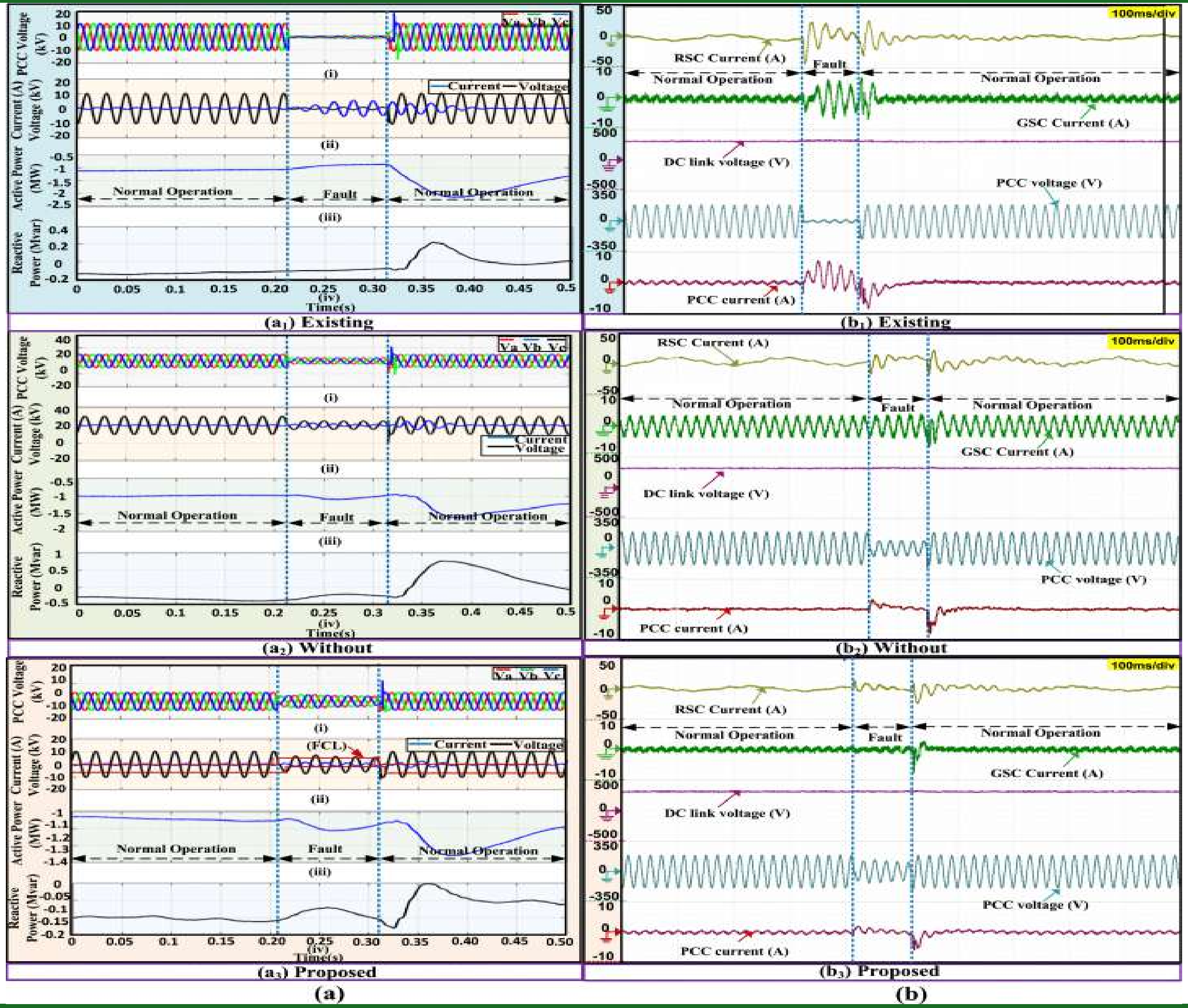
PHIL Experimentation Results

FIG.40 PHIL experimentation results for fault taking place before the FCL at second fault instant during subsynchronous operation. (a) At RTDS platform-Bus 5 results (PCC Voltage, current injected, active power, reactive power measured at PCC). (b) At FPGA platform-DFIG results (RSC current, GSC current, DC link voltage, PCC voltage and current measured at power amplifier). (a1, b1) Existing arrangement of the FCL. (a2, b2) Without FCL. (a3, b3) Proposed arrangement of the FCL.



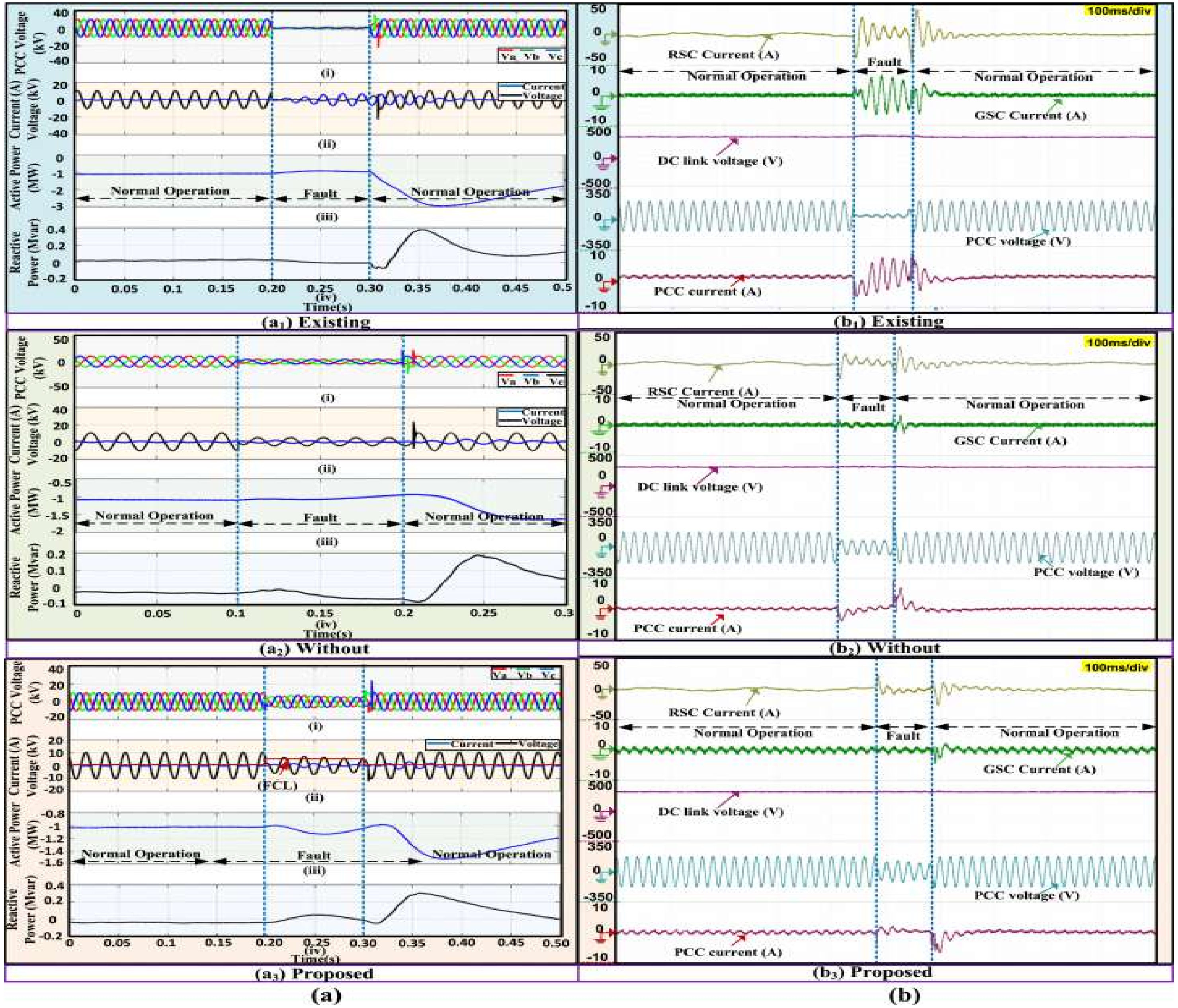
PHIL Experimentation Results

Fig. 41 PHIL experimentation results for fault taking place before the FCL at third fault instant during subsynchronous operation. (a) At RTDS platform-Bus 5 results (PCC Voltage, current injected, active power, reactive power measured at PCC). (b) At FPGA platform-DFIG results (RSC current, GSC current, dc-link voltage, PCC voltage and current measured at power amplifier). (a1, b1) Existing arrangement of FCL. (a2, b2) Without FCL. (a3, b3) Proposed arrangement of FCL.



PHIL Experimentation Results

Fig. 42 PHIL experimentation results for fault taking place before the FCL during supersynchronous mode of operation. (a) At RTDS platform-Bus 5 results (PCC Voltage, current injected, active power, reactive power measured at PCC). (b) At FPGA platform-DFIG results (RSC current, GSC current, DC link voltage, PCC voltage and current measured at power amplifier). (a1, b1) Existing arrangement of the FCL. (a2, b2) Without FCL. (a3, b3) Proposed arrangement of the FCL.



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Thank You