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A Comparative Review of Ancillary Service Markets: Benchmarking Global Practices and Implications for Indonesia

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Abstract

The rapid integration of renewable energy sources is transforming power system operations, resulting in reduced system inertia and increased operational variability. These modifications increase the demand for advanced ancillary service (AS) to ensure system stability, including frequency regulation, reserve provision, and voltage management. Unlike countries that have implemented market-based ancillary service and advanced technologies, Indonesia still operates ancillary service through centralized mechanisms with limited participation of new technologies. This report presents a comparative analysis of the development of ancillary service in selected countries by assessing aspects of market structure, pricing mechanisms, technology integration, regulatory frameworks, and operational maturity. A qualitative maturity assessment methodology is used to evaluate the level of implementation across various power systems. The findings reveal significant differences between developed and developing systems. Countries such as Australia, the United Kingdom, and the United States demonstrate more advanced maturity by incorporating rapid response technologies, competitive market frameworks, and real-time system operations. In contrast, Indonesia is still at an early stage with centralized management, limited technology integration, and the absence of a structured ancillary service market. Unlike existing comparative studies focused on OECD contexts, this paper explicitly targets the policy and implementation gap for a large, archipelagic, state utility dominated emerging economy. A five phase implementation roadmap is proposed for 2025–2034, aligned with RUPTL targets and calibrated to Indonesian institutional realities.

Keywords: Ancillary Service, Battery Energy Storage System, Benchmarking Analysis, Flexibility, Fast Frequency Response, Power System

I. INTRODUCTION

In the electricity system, the primary energy market generally operates based on the merit order principle, prioritizing generators with the lowest production costs to achieve efficiency and reduce energy supply costs (Sensfuß et al., 2008). This mechanism is implemented by considering operational constraints such as transmission network capacity and system reliability standards (N-1). However, these constraints are not yet fully capable of addressing the increasingly complex needs for system stability (Ciapessoni et al., 2017). Modern power systems require the ability to respond quickly to load changes and fluctuations in renewable energy generation, including through high ramping capability and sufficient inertia to maintain frequency stability (Milano et al., 2018). Because merit order emphasizes economic aspects, the selected generators may not necessarily have the best technical capabilities to support dynamic system stability (Ela et al., 2014).

A ramping capability deficit triggers power imbalances that lead to rapid frequency deviations, while a lack of inertia increases the RoCoF, which risks triggering a system split (Milano et al., 2018) (Kundur et al., 2004). These uncontrolled dynamic conditions systematically result in violations of reliability standards and requirements stipulated in the grid code (Matevosyan et al., 2019). Therefore, a secondary market is needed that provides ancillary service as a functional corrective mechanism and explicit economic compensation to complement the primary market, ensuring that system operations can maintain physical integrity, stability, and power quality sustainably amidst economic efficiency pressures (Rebours et al., 2007). As an effort to address the inherent failure of the primary energy market, structural reform of the electricity sector globally requires the separation of technical functions (reliability) from commercial functions (energy), or what is known as unbundling (Stoft, 2002). A direct consequence of this unbundling is the need to formulate and provide explicit remuneration for ancillary service through a separate secondary market mechanism (Pérez-Arriaga, 2013).

The objective of this research is to conduct a comparative benchmarking of five countries: the Philippines, the United Kingdom, Australia, the United States, and South Africa, across five analytical dimensions: market structure, pricing mechanisms, technology integration, regulatory frameworks, and operational maturity. It then identifies research and policy gaps in the Indonesian context and finally proposes a conceptual framework and implementation roadmap for ASM in Indonesia that is measurable and contextual.

Based on the standards set by the Federal Energy Regulatory Commission (FERC, 1996), the Ancillary service Market is defined as a vital technical function beyond the production of active energy (MWh) that ensures the security and reliability of the transmission system from generation to load. This service covers a wide spectrum ranging from the provision of synchronous inertia, primary frequency control (Frequency Containment Reserve), voltage regulation, to black start capability (Rebours et al., 2007). These functions are executed either autonomously by the governor and AVR or centrally through the AGC to maintain frequency and voltage parameters within a tight tolerance corridor when a supply-demand imbalance occurs (Wood et al., 2013). Specifically, the following diagram illustrates the main ancillary service.

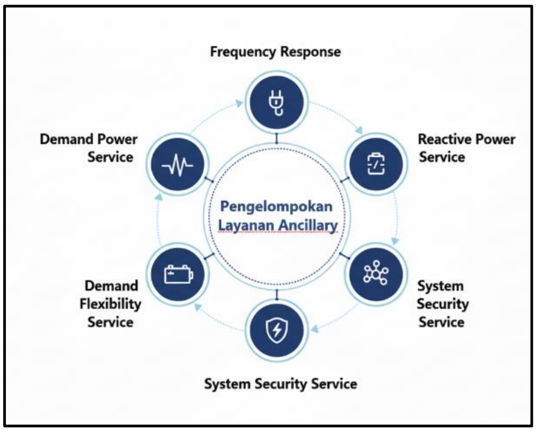

Figure 1. Ancillary Service Classification.

The classification in Figure 1 divides technical roles into several main domains.:

1. Frequency Response: Focuses on active power balance (P-f control) to respond to load fluctuations or generator trips within seconds to minutes (Kundur et al., 2004) (Rebours et al., 2007).
2. Reactive Power Service: Focuses on providing reactive power to maintain the voltage profile (Q-V control) and dynamic voltage stability (Rebours et al., 2007).
3. System Security Service: Includes services crucial for system resilience, such as Black Start for post-blackout recovery and system protection schemes (Remedial Action Schemes) to prevent cascading failures (Adibi et al., 1987).
4. Demand Power & Flexibility Service: Utilizes the load side (Demand Response) to actively participate in system balancing, either through load curtailment or flexible load shifting (Albadi & El-Saadany, 2008).

The dynamics of the national energy sector are currently moving towards a historic transformation phase along with the establishment of two strategic policy foundations, namely the 2025-2034 Electricity Supply Business Plan (RUPTL) and the Second Nationally Determined Contribution (SNDC) document (Kementerian ESDM, 2024), (Government of Indonesia, 2024). These two documents are not merely administrative targets, but rather blueprints that fundamentally change the risk profile and operational needs of the electricity system managed by PLN. In the new SNDC document, Indonesia has shifted from relative percentage-based emission reduction targets to stricter emission reduction commitments determined directly based on the number of emissions, which directly implies the need for measurable restrictions on the operation of fossil fuel power plants (Government of Indonesia, 2024). At the same time, the 2025-2034 RUPTL requires the integration of 69.5 GW of new generating capacity with a portion of intermittent New and Renewable Energy (NRE), especially Solar Power Plants (PLTS) of 17.1

GW and Wind Power Plants (PLTB) of 7.2 GW, which will dominate the energy mix (Kementerian ESDM, 2024). The convergence between the SNDC's absolute decarbonization obligations and the massive penetration of Variable Renewable Energy (VRE) creates an unavoidable urgency for PLN to adopt the Ancillary Services Market mechanism as an instrument to mitigate operational and financial risks (Cochran et al., 2014).

Power outages or total system failures are the most fatal consequences in the operation of an Electric Power System (ESP), indicating a major breakdown in the balance between supply and demand. The risk of these catastrophic events is expected to increase with the aggressive penetration of VRE, primarily due to the loss of system inertia (Alhelou et al., 2019). Power outages or total system failures are the most fatal consequences in the operation of an Electric Power System (PLTS), indicating a major breakdown in the balance between supply and demand. The risk of these catastrophic events is expected to increase with the aggressive penetration of VRE, primarily due to the loss of system inertia (Alhelou et al., 2019). To mitigate these fatal risks, the implementation of comprehensive ancillary services is absolutely necessary. Unlike conventional systems that focus solely on active power supply, the AS market provides a multi layered defense. Services such as Frequency Response and System Security Services like Black Start and Corrective Action Schemes function as automated "immune systems" that respond to disturbances within milliseconds (Rebours et al., 2007) (Adibi et al., 1987). The effectiveness of these mechanisms has been demonstrated in the case of the Queensland system, Australia, where the rapid activation of AS responses prevented disturbances from developing into blackouts. Conversely, the absence of reliable AS mechanisms in systems with high VRE penetration would only allow minor disturbances to escalate into total system failures, as began to occur globally after 2016 (Alhelou et al., 2019) (Tielens & Van Hertem, 2016).

Therefore, the establishment of a structured Ancillary Services Market is not only about efficiency, but also a hedging strategy for PLN to ensure that the RUPTL and SNDC 2025-2034 targets can be achieved safely and financially (Kementerian ESDM, 2024), (Government of Indonesia, 2024). This market will be key to unlocking investment viability for the planned 10.3 GW energy storage target, as BESS technology requires revenue streams from frequency stability services to achieve its economic viability (Castillo & Gayme, 2014). Furthermore, this mechanism allows PLN to optimize its existing thermal generation assets by providing fair compensation for its new role as a flexibility provider, no longer just a baseload kWh provider (Gonzalez-Salazar et al., 2018). However, power outages are not just a technical issue, but also a multifaceted financial event that can cost billions of dollars in a matter of hours. If the costs of resilience tactics are included, the GDP loss from a two-week power outage can reach USD 17 billion for a single metropolitan area (Peterson et al., 2025). Therefore, the initiative to develop a

Supporting Services Market is a progressive step that will strengthen PLN's position as an energy transition regulator, ensuring that Indonesia's green ambitions go hand in hand with world-class electricity supply reliability standards (Pérez-Arriaga, 2013).

II. METHODOLOGY

This study employs a structured qualitative comparative analysis (SQCA) approach combining systematic literature review, policy document analysis, and multi-dimensional benchmarking. This approach was selected because the development of an ancillary services market is not purely a market economics problem, it is inherently multi-dimensional, intersecting dynamic stability, system reliability, institutional design, and technological readiness (Laguna-Estopier et al., 2024).

Secondary data was obtained from scientific publications (Scopus, Web of Science, ScienceDirect, and IEEE Xplore) as well as policy documents from regulators, system operators, and electricity market organizers. The selected benchmark countries the Philippines, Australia, the United Kingdom, the United States, and South Africa were determined based on the maturity of their ancillary services markets, renewable energy penetration, market model diversity, similarities in operational challenges with Indonesia, and the completeness of their technical and regulatory documentation.

Figure 2 illustrates that the research began with a literature review and data collection, followed by international benchmarking using five analytical dimensions: Regulatory Frameworks, Market Structure, Pricing Mechanisms, Technology Integration, and Operational Maturity. The benchmarking results were used to identify gaps between Indonesian conditions and international best practices, which then served as the basis for developing a transformation strategy and an ancillary services implementation roadmap. The final stage of the research was the preparation of conclusions summarizing key findings and strategic recommendations for the development of the ancillary services market in Indonesia.

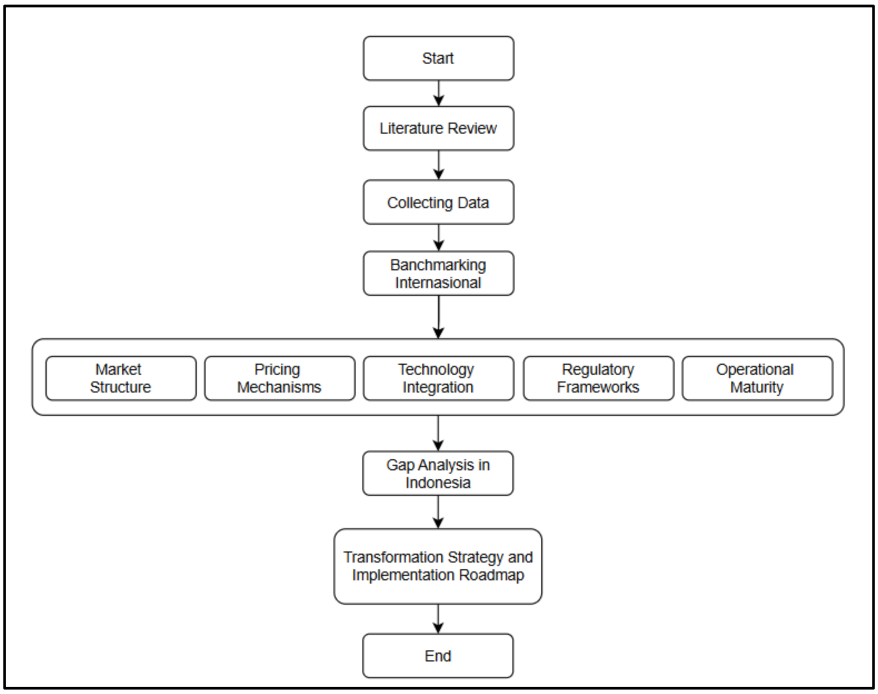

Figure 2 Research Workflow

III. DISCUSSION

III.1. Benchmarking Result

The experiences of the Philippines and Australia demonstrate that co-optimizing energy and reserves within a single platform is more efficient than separate procurement. Market operator independence is a key success factor, as implemented by IEMOP, AEMO, and NESO. Australia also demonstrates the effectiveness of causer-pays schemes in encouraging behavior that supports system reliability. As VRE penetration increases, BESSs are becoming the primary provider of high-speed ancillary services, leaving countries that have not yet developed them at risk of lagging behind in system reliability. Furthermore, Australia's experience underscores the importance of technology-neutral regulation, while the UK demonstrates the need for a transparent and long-term market development roadmap to provide certainty to industry players. Benchmarking results are presented in Table 1.

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Table 1. Five Country Ancillary Services Market Benchmarking Matrix

Dimension	Philippines	Australia	United Kingdom	United States	South Africa
Market Structure	Co-optimized energy & reserve market (WESM); single MMS dispatch; bilateral ASPAs transitioning to competitive reserve market (FCO Jan 2024)	Co-optimized NEM dispatch; 8 FCAS products + Very Fast (VF) FCAS; multi-stakeholder AEMO	Dynamic auctions (DC/DM/DR); periodic procurement; NESO Product Roadmap (ARU)	6 RTO/ISO regions; varied products per region; competitive LMP-based dispatch	CWEM in transition; administered NERSA tariff; ancillary services planned incrementally; NTCSA licensing Nov 2025
Pricing Mechanism	Competitive auction; periodic clearing; penalty relaxation during Trial Operations (TOP)	Causer-pays + market clearing per 5-min interval; strongest grid-friendly incentive structure	Periodic auction; competitive clearing price; long-term contracts for capacity certainty	Locational marginal pricing (LMP) + ancillary service clearing; RTO tariffs	NERSA administered tariff; competitive market clearing not yet operational
Dominant Technology	Gas, coal, hydro + early BESS/VRE; BESS registration framework being established	BESS (>1 GW projected 2026); wind, solar, gas peakers; BESS Guide to Contingency FCAS	BESS (>2 GW installed); demand response; gas; DER aggregation (VPP)	BESS (dominant in CAISO/PJM); demand response; gas; DER via FERC Order 2222	Gas, coal, hydro (Eskom dominated); BESS not yet significant; early-stage IPP RE
Regulatory Framework	DOE Notice 2024-01-001-SEC; ERC Order 2023-002 RC; EPIRA 2001 as foundation	NER; AEMC Rules; IESS Rule 2021 (technology-neutral); AEMO BESS Guide	NESO ARU Framework; technology-neutral product definitions; long-term market roadmap	FERC Orders 841 & 2222; technology-neutral; BESS and DR explicitly accommodated	ERAA 2024; National Energy Act; Draft Wholesale Market; structural unbundling incomplete
Operational Maturity	Medium — developing (FCO Jan 2024); 98.39% reduction in grid	Very High — active market >20 years; dynamic product	High — dynamic product evolution; managing VF FCAS	High — >20 years; most comprehensive regulatory template;	Low–Medium — structural transition; key challenges: Eskom unbundling

III.2. Universal Patterns: Three Invariants of Success

From the analysis of the matrix cells in Table 1, three success factors were identified that consistently emerged in countries with ancillary service markets with a high level of operational maturity:

1) Operator Independence: Every successful ancillary service market has an operator independent of the commercial interests of both generators and transmission. IEMOP (Philippines), AEMO (Australia), NESO (UK), and FERC+RTO (USA) are all multi-stakeholder, non-profit structures without commercial conflicts of interest. South Africa, which is just beginning its NTCSA transition, faces the greatest risk from Eskom's legacy of conflicting interests.

2) Energy and Reserve Co-Optimization: The most cost-efficient markets are those that optimize energy and reserves simultaneously within a single dispatch algorithm (Australia, the Philippines, and some RTOs in the US). Procuring ancillary services separately from energy results in systemic sub-optimization.

3) Technology-Neutrality of Regulation: A successful regulatory framework defines performance requirements (response time, accuracy, sustained capability) rather than the type of technology that must be used. Australia's IESS Rule 2021, FERC Orders 841 & 2222, and the NESO ARU framework are all technology-neutral, allowing BESS, demand response, and DER to compete based on technical capabilities, not asset categories.

III.3. Technology Architecture: The Inevitable BESS Revolution

Analysis of the Dominant Technology dimension reveals one inescapable trend. BESS is replacing gas peakers as the technology of choice for fast response ancillary services. Australia (>1 GW projected), the UK (>2 GW installed), and California/USA are already in this phase. The Philippines is just getting started. South Africa has not yet started.

The primary driver of this shift is the trifecta of BESS advantages: (1) sub-second response times unmatched by thermal technologies; (2) near-zero marginal cost to operate; and (3) an 80%+ reduction in BESS capital costs over the past decade. Any jurisdiction that is slow to integrate BESS into its ancillary service framework will face a reliability gap as VRE increases.

III.4. Maturity Gradient: From Transition to Saturation

The matrix reveals a clear maturity gradient, as shown in Figure 3. This gradient is not simply chronological, it reflects the institutional, technological, and market complexities that must be built sequentially.

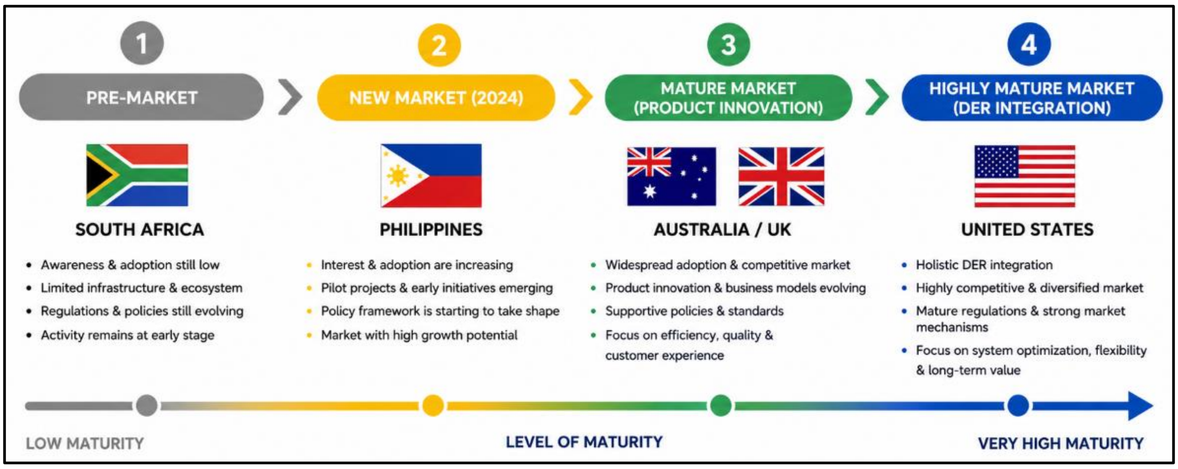

Figure 3 Market maturity gradient (ERAA 2024)

The figure above represents The Philippines demonstrates that the leap from a bilateral ASPA to a jointly optimized market can be achieved within seven months of Pilot Operations if the IT, regulatory, and institutional foundations are in place. South Africa, on the other hand, demonstrates that without such a foundation, even with sound regulations (ERAA 2024), implementation can take a decade.

The challenges of maturity (UK, Australia) are fundamentally different from those of the early stage (South Africa). The UK and Australia face challenges of market saturation and revenue diversification, reflecting the challenges of highly mature markets. South Africa, on the other hand, faces challenges of separation and human resources, related to existential issues that determine whether the market will ever exist.

III.5. Critical Success Factors (CSF)

Each CSF is evaluated using three dimensions: universality (applicability in how many countries it applies), magnitude (impact), and transferability (transferability) to determine how easily it can be transferred to the Indonesian context. Of the seven CSFs identified in Table 2, three have the highest priority for Indonesia, based on a combination of impact magnitude and urgency of action:

a) Institutional Independence of Market Operators

Market operator independence is a key requirement for creating a credible and investment-attracting ancillary services market. This reform requires regulatory changes, as PLN still performs multiple functions. South Africa's experience shows that the reform process can take three to five years.

b) A Capable Market Management System (MMS)

An MMS capable of real-time co-optimization of energy and reserves is the technical foundation of the ancillary services market. The investment in an MMS is relatively small compared to the potential losses resulting from inefficient ancillary services management.

c) Regulatory Clarity with Technology Neutrality

Regulations need to focus on performance standards, not technology types, to avoid stifling innovation. Furthermore, cross-regional coordination is crucial to support system integration and the development of an efficient ancillary services market.

III.6. Four Internationally Proven Practices for Adaptation

The findings of this study identify several policy practices, market designs, and operational mechanisms that have the potential to be adapted to accelerate the development of the ancillary service market in Indonesia.

1. Adopt the Philippine IEMOP Model: Integrated MMS. The Philippines' model of co-optimized energy and reserve markets within a single MMS is relevant for Indonesia due to its similar system

characteristics. The Indonesian MMS needs to support regional clearing with inter-regional reserve coordination. The estimated MMS investment ranges from USD 40–80 million.

2. Trial Operations Program (TOP) before Full Commercial Operation. The Philippines' experience shows that TOP is effective for testing MMS, identifying compliance gaps, improving market participant readiness, and refining transaction settlement mechanisms before full commercial operation. Indonesia could implement TOP on its JAMALI system in 2028–2029 before the FCO in 2030.

3. BESS Guidelines and Technology-Specific Technical Guidelines. Australia has demonstrated that BESS-specific technical guidelines can reduce regulatory uncertainty and encourage investment. Indonesia should issue guidelines for BESS participation in ancillary services 2–3 years before market launch.

4. Regulatory Sandbox in Isolated Systems. Australia's regulatory sandbox model allows for the testing of new technologies before full market entry. Indonesia can implement BESS sandboxes in smaller systems such as Sulawesi, NTT, or Kalimantan to build operational experience and technical capabilities with lower risk.

Table 2. Critical Success Factors Comparative Benchmarking Matrix

Critical Success Factors	Deskrips	Benchmark Referensi	Universalitas – Magnitude - Transferability
*Independensi Operator	Pemisahan fungsi TSO dan market operator dari entitas PLN yang terintegrasi vertikal	IEMOP (Filipina), AEMO (Australia), NESO (UK)	5/5 – Kritis - Sedang
*Regulatory Clarity	Peraturan teknis yang jelas tentang definisi produk, persyaratan kualifikasi, mekanisme sertifikasi, dan sanksi kepatuhan	ERC Order 2023-002 RC (Filipina), AEMC Rules (Australia)	5/5 – Tinggi - Tinggi
*Market Management System	Platform teknologi yang mampu co-optimisasi energi dan cadangan secara real-time dengan settlement otomatis	IEMOP MMS (Filipina), AEMO EMS (Australia)	5/5 – Kritis - Tinggi
Technology Inclusion Policy	Kebijakan yang secara eksplisit mengakomodasi BESS, VPP, dan DER dalam peran anciary service	AEMO BESS Guide (Australia), FERC Order 2222 (AS), NESO ARU (UK)	5/5 – Tinggi - Tinggi
Capacity Building Berkelanjutan	Investasi SDM di PLN, regulator, IPP, dan akademisi tentang ancillary service market design dan operasi	AEMO Technical Workshops, FERC compliance support	5/5 – Tinggi - Tinggi
Sequencing yang Tepat	Melakukan uji coba teknis dan pilot sebelum full commercial operations; memulai dari produk sederhana	Filipina (TOP → FCO), Afrika Selatan (energy → ancillary services)	4/5 – Tinggi - Sangat Tinggi
Insentif Investasi BESS	Kerangka pembiayaan yang memungkinkan BESS mendapatkan pendapatan dari multiple streams (energy + ancillary service)	UK BESS revenue model, IRR 10-15% proyeksi Indonesia (SUPRA, 2025)	3/5 – Tinggi - Sedang
Koordinasi Lintas-Wilayah	Mekanisme koordinasi ancillary service antara JAMALI, Sumatera, Sulawesi, Kalimantan sebagai sistem yang semakin terinterkoneksi	NEM multi-region Australia, WESM Luzon-Visayas-Mindanao (Filipina)	5/5 – Tinggi - Koordinasi Lintas-Wilayah

III.7 Limitations of Study

Several limitations of this study must be acknowledged. First, all data is secondary, no primary field surveys, stakeholder interviews, or system simulations were conducted the gap analysis relies on publicly available regulatory documents and published literature. Second, Indonesia's regulatory environment is evolving rapidly, some conditions described may have changed since data collection. Third, the benchmark does not include hybrid Asian market models such as Japan, South Korea, or India, which could provide additional relevant comparators for Indonesia's transition stage. Fourth, the BESS IRR projection cited in the CSF matrix carries substantial uncertainty pending actual Indonesian ancillary service tariff design decisions. Future research should incorporate power system simulation of the JAMALI system under high VRE penetration scenarios and primary data collection from Indonesian stakeholders.

III.8. Implications for Indonesia

Based on a synthesis of analysis across all dimensions and across the five countries, the five main priorities for developing ancillary services in Indonesia are:

1) Separate the Market Operator function from PLN. Independence is a non-negotiable prerequisite. The Philippines' IEMOP model is the most applicable reference for the Southeast Asian context.
2) Invest in a co-optimized Market Management System (MMS). The technical platform is the backbone of the market. Without an MMS capable of real-time co-dispatching of energy and reserves, no market can function.
3) Issue a technology-neutral regulatory framework for BESS. Modeled after Australia's IESS Rule 2021, Indonesian regulations should explicitly accommodate BESS as ancillary service providers equivalent to conventional generators.
4) Establish a regulatory sandbox in isolated systems. Prior to national implementation, pilot BESS in Sulawesi or East Nusa Tenggara (NTT) with structured ancillary service roles to establish track records and technical capabilities.
5) Design an attractive BESS revenue stack from the outset. Following lessons from the UK on saturation, ensure the BESS can generate revenue from multiple streams (ancillary service + balancing + energy arbitrage) to ensure long-term investment viability.

III.9. Indonesia Ancillary Service Development Roadmap (2025–2034)

Table 3 explains the proposed roadmap is based on two key national policies: the 2025–2034 RUPTL (42.6 GW of renewable energy + 10.3 GW of storage) and the 2025–2060 RUKN (34 GW of storage; 41.6% VRE penetration by 2060). The significant increase in variable resources makes ancillary services a strategic element in maintaining grid reliability. The roadmap consists of five phases over nine years, faster than the Philippines' 23-year trajectory (EPIRA 2001 to FCO 2024) as Indonesia can readily adopt proven best practices and avoid known mistakes. Three non-negotiable prerequisites apply: (1) political commitment to the separation of PLN functions beginning in 2025; (2) MMS financing allocated as a priority in the JETP and the 2026 APBN; and (3) BESS Technical Guidelines issued by 2027.

Table 3. Indonesia Ancillary Services Market Development Roadmap (2025–2034)

Period & Name	Key Actions	Responsible Actor	Success Indicator
2025–2026 Foundation	• Political commitment to PLN function unbundling • Draft AS Market Regulation (GR level) • Publish BESS Technical Guideline • Establish AS Market Task Force (MEMR + PLN + DEN) • JETP financing allocation for MMS	MEMR (regulator) DEN (planning) DPR (legislative)	Law 30/2009 amendment initiated; MMS budget in APBN 2026
2027–2028 System Development	• Procure/develop co-optimized MMS (USD 40–80M) • BESS Regulatory Sandbox (Sulawesi/NTT isolated systems) • Train PLN P2B, IPPs, and regulator staff on AS market operations • Draft AS Market Rules and Grid Code amendments	PLN (operational) JETP Secretariat (financing) ARENA-equivalent (sandbox)	MMS operational in test environment; ≥3 BESS projects registered in sandbox
2028–2029 Trial Operations (TOP)	• JAMALI AS Market Trial Operations (penalty relaxation) • Market participants bidding in frequency reserve products • Real-time MMS co-dispatch of energy and reserves • Settlement parameter calibration • Compliance gap identification	Independent Market Operator PLN (generator/provider) IPPs	≥10 providers registered; frequency deviation within ±0.2 Hz 95% of time
2030–2031 Full Commercial Ops	• JAMALI AS Market Full Commercial Operations (FCO) • Technology-neutral participation (BESS, DR, VRE synthetic inertia) • Sumatra AS Market pilot (TOP) • Cross-regional reserve coordination JAMALI–Sumatra	Independent Market Operator MEMR (regulatory oversight) All registered providers	AS cost reduction ≥15% vs pre-market baseline; BESS AS revenue viable at market price
2032–2034 National Expansion	• Sulawesi and Kalimantan AS Market integration • Multi-stream BESS revenue stack fully operational • VRE synthetic inertia products introduced • Performance review and market design refinement • Full alignment with RUPTL 2025–2034 and SNDC targets	All market operators All regions MEMR + DEN + PLN	41.6 GW VRE integrated with grid stability maintained; system inertia adequate to ROCOF ≤ 0.5 Hz/s

IV. CONCLUSION

This paper has conducted a systematic comparative analysis of ancillary services market designs across five jurisdictions the Philippines, Australia, the United Kingdom, the United States, and South Africa across five analytical dimensions. It has applied these findings to identify gaps and develop a context-specific roadmap for Indonesia. Three universal invariants of ASM success are identified institutional independence of the market operator, co-optimization of energy and reserves within a single dispatch algorithm, and technology-neutral, performance-based regulation. All three are currently absent from Indonesia's centralized AS management model.

The Philippines demonstrates that emerging economies in Southeast Asia, with characteristics very similar to Indonesia, can build functionally optimized markets within a measurable timeframe. The 98.39% reduction in grid standby costs within twelve months of the Reserve Market implementation provides quantitative evidence of the operational value of a well-designed ASM. Australia demonstrates that continuous product innovation can maintain market efficiency as the generation mix evolves. The United Kingdom warns of single-product market saturation. The United States offers the most comprehensive regulatory template for BESS participation and demand response. A key lesson from South Africa is building a supporting services market that is not only technically functional but also equitable in terms of technology access, transparent in pricing, and resilient to the inevitable volatility of the energy transition. The proposed five-phase roadmap (2025–2034) aligns with RUPTL and SNDC targets and is calibrated to Indonesia's institutional realities. Its three non-negotiable preconditions, PLN unbundling commitment, MMS investment, and BESS Technical Guidelines are the minimum institutional prerequisites for accelerated implementation. Without these, the energy transition targets of RUPTL and SNDC cannot be achieved with adequate system reliability. Future research should complement this qualitative benchmarking with power system simulation of JAMALI under high VRE penetration scenarios, quantitative inertia analysis to determine critical AS procurement thresholds, and primary stakeholder research on institutional barriers to PLN unbundling.

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