DESK STUDY ON TECHNICAL GAPS OF COUNTRY-SPECIFIC GRID CODES AND REGULATIONS AND RECOMMENDATIONS FOR A COMMON ASEAN WIDE-GRID CODE

USAID CLEAN POWER ASIA

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ACRONYMS

AC	Alternating Current
ADB	Asian Development Bank
AEDP	Alternative Energy Development Plan
AERN	ASEAN Energy Regulators Network
AGC	Automatic Generation Control
AMS	ASEAN Member States
ASEAN	Association of Southeast Asian Nations
ATC	Available Transfer Capacity
AVR	Automatic Voltage Regulator
BESS	Battery Energy Storage System
DAM	Day-Ahead Market
DC	Direct Current
DEPP	Department of Electric Power Plant
DOE	Department of Energy
EAC	Electricity Authority of Cambodia
EdC	Électricité du Cambodge
EDL	Électricité du Laos
EGAT	Electricity Generating Authority of Thailand
EPGE	Electric Power Generation Enterprise
EPIRA	Electric Power Industry Reform Act
EPPO	Energy Policy and Planning Office
EPSN	Electric Power System Network
ERAV	Electricity Regulatory Authority of Vietnam
ERC	Electricity Regulatory Commission
ESE	Electricity Supply Enterprise
FiT	Feed in Tariff
FRT	Fault Ride Through
GENCO	Generation Corporation
GMS	Greater Mekong Subregion

HAPUA	Head of ASEAN Power Utilities/Authorities
HFO	Heavy Fuel Oil
HVDC	High Voltage Direct Current
IDM	Intra-Day Market
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
LFSM	Limited Frequency Sensitive Mode
Lao PDR	Lao People's Democratic Republic
LM	Lower Mekong
LVRT	Low Voltage Ride Through
MEA	Metropolitan Electricity Authority
MEMR	Ministry of Energy and Mineral Resources
MIME	Ministry of Industry, Mine and Energy
MOEE	Ministry of Electricity and Energy
MOEP	Ministry of Electric Power
MOIT	Ministry of Industry and Trade
MPE	Moeller-Poeller Engineering
NEA	National Electrification Administration
NEDA	New Enhanced Dispatch Arrangement
NGCP	National Grid Corporation of the Philippines
NVE	Norwegian Water Resources and Energy Directorate
PDP	Power Development Plans
PEA	Provincial Electricity Authority
PLN	Perusahaan Listrik Negara
PMU	Phasor Measurement Units
PPA	Power Purchase Agreement
PV	Photo Voltaic
RE	Renewable Energy
REE	Rare Earth Elements
REGP	Renewable Energy Generation Plants

RPTCC	Greater Mekong Subregion Economic Cooperation Program, Regional Power Trade Coordinating Committee
SCADA	Supervisory Control and Data Acquisition
SCR	Short Circuit Ratio
SEB	Sarawak Energy Berhad
SESB	Sabah Electricity SdnBhd
SHS	Solar Home System
SOE	State-Owned Enterprise
SPP	Small Power Producer
TNB	Tenaga Nasional Berhad
TRANSCO	Transmission Corporation
TSO	Transmission System Operator
TTC	Total Transfer Capability
UNITEN	University Tenaga Nasional
VRE	Variable Renewable Energy
VSPP	Very Small Power Producer
WG	Working Group
YESC	Yangon City Electricity Supply Corporation

ACKNOWLEDGMENTS

This report was prepared by the Asian Institute of Technology (AIT). AIT was engaged by Abt Associates to conduct a review of the grid codes of ASEAN-member states and the proposed regional grid code for the Greater Mekong Subregion, identify the technical gaps of country-specific grid codes and regulations with respect to Variable Renewable Energy (VRE) integration and regional interconnection, and provide a recommendation for a common ASEAN-wide grid code.

Delphos International and AECOM New Zealand Ltd. (the Delphos Team) were contracted separately by Abt Associates to conduct a transmission desk study which required information from this grid codes gap analysis. Therefore, Delphos and AECOM reviewed AIT's desk study draft and final report and provided comments and suggested changes. Also, Abt Associates shared the latest and translated grid codes of Thailand, Lao PDR, and the Philippines and engaged the Delphos Team to update the relevant sections of this report to reflect those documents.

Although this report is predominantly AIT's work, the Delphos Team has made material changes to AIT's conclusions and recommendations in some cases. The updates to AIT's final draft made by the Delphos Team were constrained by the budgeted time as well as the contents of AIT's report.

The authors would like to gratefully acknowledge the support and guidance of USAID Clean Power Asia's Chief of Party Dana Kenney, and Renewable Energy Policy Expert Thanawat Keereepart who contributed their regional knowledge, as well as their technical and managerial expertise, to this report.

EXECUTIVE SUMMARY

A regional grid code provides a coherent framework within which a regional power system can be operated efficiently and reliably. The main objective of this report is to recommend the basis for a common ASEAN-wide grid code and to conduct a desk study on the technical gaps of national grid codes and regulations with respect to a potential ASEAN-wide grid code. The gap analysis was limited to the following countries: Cambodia, Lao People's Democratic Republic (Lao PDR), Myanmar, Thailand, Vietnam, Indonesia, Malaysia and Philippines, i.e., all ASEAN countries except for Singapore and Brunei.

Key findings are summarized below:

1. Considerable progress has been made towards a sub-regional harmonization of grid codes under the Greater Mekong Subregion (GMS) framework. Through extended stakeholder consultation and analysis, a GMS Regional Grid Code (GMS RGC) has been prepared. Given the groundwork that has been laid, it is recommended that the GMS RGC form the starting point for an ASEAN-wide grid code, with participation of Indonesia, Malaysia, Singapore, and the Philippines in future refinements to the GMS RGC.

2. The GMS RGC has been formulated based upon the European (ENTSO-E) model. The European electricity market has matured over the years with strong grid infrastructure, uptake of technologies such as FACTS, HVDC, inverter-based grid supporting generators, and well-formed national grid codes; the development of national markets within the GMS has not benefitted from such features. In some cases, therefore, the GMS RGC is more stringent than the national-level grid codes. (Inevitably, a regional grid code will be initially misaligned with national-level grid codes in some areas).

3. With respect to Variable Renewable Energy (VRE), for most of the technical requirements, the GMS RGC recommends that individual Transmission System Operators (TSOs) stipulate the operating thresholds, including ride-through criteria. This approach could lead to conflict and grid instability, especially with AC-based cross-border transmission interconnections that already exist (there is already grid synchronization between Lao PDR and Thailand and between Vietnam and Cambodia). Such requirements must be addressed in consultation with the national TSOs.

4. A gap analysis was conducted by comparing the GMS RGC – as the basis for an ASEAN-wide grid code – with the existing grid codes of the abovementioned countries. In summary, the gap analysis found the following:

    a. <u>Lao PDR</u>: The domestic HV grid in Laos is synchronized with Thailand's grid and controlled in large part by Thailand's EGAT. There is no mechanism for Under-Frequency Load Shedding (UFLS), and a Manual Load Shedding (MLS) scheme is used in emergency situations. It is not clear what the allowable range of power flow on

EDL's grid is when the grid is in an emergency state. The allowable range of power flow on international tie-lines is not clear. Phase angle stability requirements are unclear. In 2020, under the USAID Clean Power Asia program, and in coordination with EDL, the Hawaii Natural Energy Institute developed proposed Solar Photovoltaic Generating Facility Interconnection Standards and in 2021 developed proposed Inverter-based Generating Facility Transmission Interconnection Standards. Implementation of the proposed standards would address gaps in Lao PDR's existing grid code with regards to connection and operating codes relevant to inverter-based VRE generation. For export IPP sales to Thailand, the generation and dedicated transmission are operated by Thailand's EGAT. EGAT requires these projects to follow EGAT's connection, operations and service codes.

b. Myanmar: A draft grid code for synchronous generators (hydro and thermal power plants) has been prepared. Although the document has not been formally adopted, power system authorities and local IPPs often refer to this draft grid code for their planning, connection, and operation. There are national guidelines standards, and specifications for Secondary Systems and Protection of HV substations (230 kV and 132 kV) based on international standards such as IEEE, IEC, and ANSI. With respect to VRE, since the draft grid code does not address asynchronous generators, authorities have benefitted from technical assistance (in connection with a recent solar PV tender) recommending the technical requirements to connect solar plants to the grid, including technical specifications for inverters and other key solar plant equipment.

c. Cambodia: The national grid is synchronized with Vietnam and to a large extent operated by Vietnam. The grid code (together with other associated legal documents) falls short of regional and international best practices in various ways, including that it does not specify operational planning and scheduling requirements regarding generator availability; it does not specify load frequency control and reserves requirements, market policies or codes, capacity allocation and congestion management, or electricity balancing. Also, while the grid code itself does not provide any guidelines with regards to asynchronously connected generators, regulations were issued in 2018 for connecting solar PV plants to the grid, which include process and technical rules regarding interconnection as well as certain operational restrictions.

d. Vietnam: The grid code has robust metrics for supply reliability targets (in terms of voltage levels, frequency, stability, allowable variations under normal and emergency conditions, power quality, permissible harmonics, voltage flicker, maximum short circuit levels) and other indications of commitment to maintain customers' quality of supply and customer service. All provisions are comparable with accepted standards and would provide no foreseeable impediment to regional integration. Several deficiencies were identified, however, in the area of transmission planning.

e. The Philippines: The country has updated its grid code for VRE interconnection and adopted a comprehensive VRE forecasting framework. The grid code and wholesale electricity market rules provide a strong enabling framework.

f. Indonesia: There are multiple deficiencies, including: (i) the relevant documents are in general too brief regarding technical requirements; (ii) the transmission codes require no specific fault behavior from generators; (iii) additional requirements for Fault Ride through (FRT) and time limited operation outside of the normal frequency range should be added; SCADA connection is required under the transmission codes, but no information on the used protocols is given in the connection code; and (iv) a large part of PLN Interconnection Guideline for Renewable Energy is dedicated to the connection of small renewable projects to distribution lines compared to the connection process to transmission lines.

g. Thailand: The revised EGAT grid code from 2019 has addressed some of the previous gaps, such as a lack of a clearly defined application and connection processes. The Connection Code now appears to be complete. There are specific data and operational requirements for solar, wind, and battery storage. Several updates have also been made to the operating requirements for generators.

h. Malaysia: The current documents governing grid code matters in Malaysia address most requirements for grid operations, at least partially. There are, however, some potential areas for improvement. For instance, voltage control from generators smaller than 5 MW is neither required nor allowed. Even if the functionality is currently not used, the capability to control the voltage at the connection point with reactive power should be required for the future, especially if there is a proliferation of smaller solar PV projects under the 5 MW threshold. Similarly, solar PV penetration limits for feeders should be determined on a regular basis instead of setting fixed limits, with additional studies mandated by the grid code or guidelines if a certain threshold is crossed. The lack of detailed requirements in the Sabah/Labuan grid code should be addressed. It may be sensible to adopt an adapted Malaysian Grid Code for Sabah/Labuan and Sarawak as they are structurally similar.

5. Although the gaps identified above could be addressed through negotiation and consultation to formulate an effective GMS RGC / ASEAN-wide grid code that could facilitate a harmonized grid, the greater challenge for a prospective regional market and grid code lies with how far some countries lag the more advanced markets. In particular, there are considerable technical gaps in planning and operations in Myanmar, Lao PDR, and Cambodia that may impede regional integration efforts. As a starting point, the GMS RGC can provide these countries with a reference for national grid code improvements, as well as to the sorts of planning and operational changes that would be required to participate in a robust regional market.

1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVE

Power sector reforms aim to provide safe, reliable, efficient and affordable power for electricity consumers. The unbundling process of liberalization, in which vertically integrated utilities were split into their generation, transmission, and distribution businesses and often privatized, made the formulation and implementation of grid codes necessary. The increasing numbers of private generators and the separation of generation from operation of the network required clear rules on how these new generators should connect to, and operate on, the national grid. A grid code thus is critical in developing, operating, and maintaining the power grid; it is even more important when cross-border grid-to-grid interconnections are added.

A grid code increases transparency and provides equal treatment by applying the same rules to all. Like other governing frameworks, grid codes should be continuously adapted to changing technologies, system conditions, and political aspirations.

Internationally, there are numerous efforts to expand regional power trade, including in ASEAN and in the Greater Mekong Sub-region (GMS), which includes five countries from the Lower Mekong area (which are also ASEAN member states) plus China. Such regional markets require a common grid code to facilitate operation of the market and trade in the market.

Within the GMS, an initiative to develop a regional grid code has been ongoing for nearly 20 years. The initiatives under the GMS and ASEAN frameworks aim to facilitate the eventual development of an ASEAN wide grid code which can enhance power trade among the ASEAN member states while satisfying the reliability and stability requirements of the system.

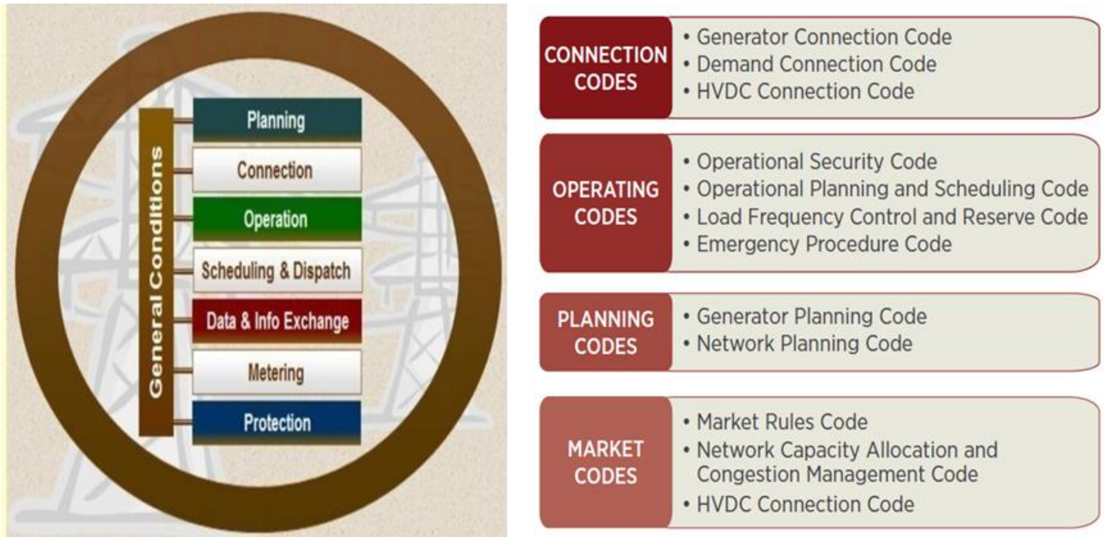
The objective of this report is to recommend a minimum grid code for Southeast Asian countries to (a) improve stability and reliability of the domestic grids and interconnections in Southeast Asia, (b) facilitate bilateral and multilateral trade in the region, and (c) increase the ability of power grids in Southeast Asian countries to accommodate higher levels of Variable Renewable Energy.

1.2 INTRODUCTION TO GRID CODES

An electric power system is a large, complex system involving different entities executing their respective activities and responsibilities. The power sector institutional setup is also changing from the vertically integrated structure where all the generation, transmission, distribution assets were owned and operated by one or a few government-owned or heavily-regulated companies. A de-regulated structure is emerging with many private generation and distribution entities and a functional electricity market where power, energy, ancillary services etc. are bought and sold. In such a scenario, for safe and reliable operation of the grid, the generation and distribution licensees, system operators and other participants in system operation should function in proper co-ordination with each other and follow the regulations, standards and procedures established by the concerned agencies.

A grid code is a technical document containing rules, procedures, guidelines, criteria, and responsibilities to be complied with by the users, owners, and operators of the transmission system. A grid code also provides basic planning, design criteria and operational rules and responsibilities of all stakeholders of the power system. A grid code mainly consists of connection codes, operating codes, planning codes, and market codes, as illustrated in Figure 1. A grid code is usually approved by a regulatory body or government in exercise of powers conferred to it under the relevant electricity law or regulation.

Figure 1. Grid Code Structure and Types of Codes that Form a Grid Code

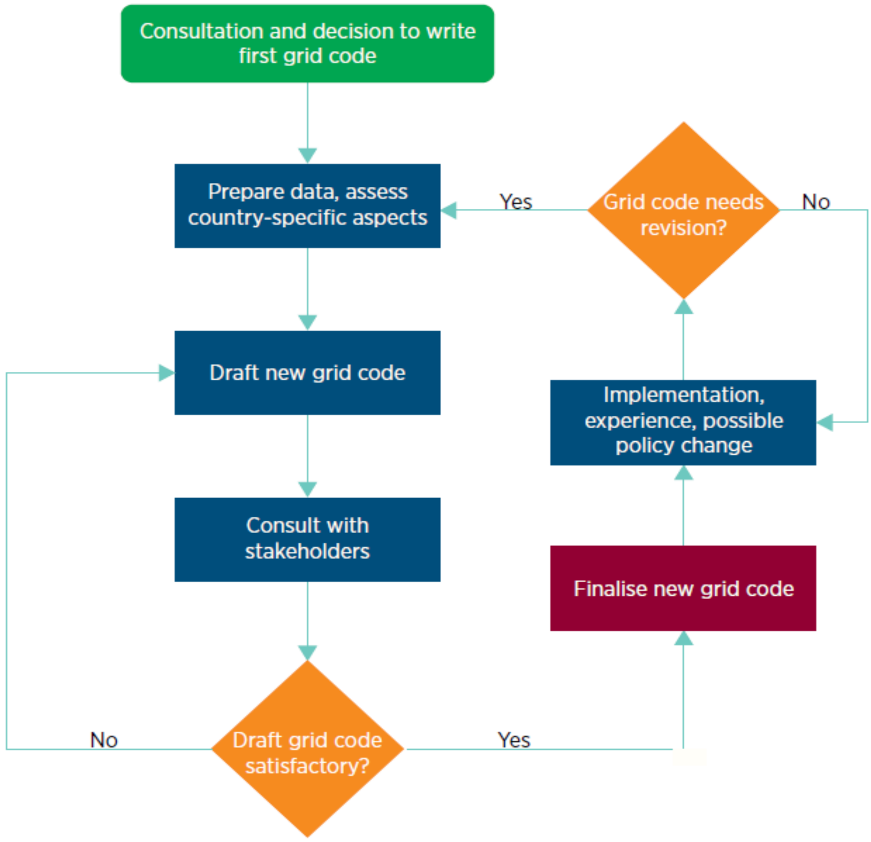


Source: Authors

In a grid code, there are many rules and criteria dealing with system operation, generation, transmission, distribution, protection, metering, maintenance, buying and selling power, ancillary services, etc. The electricity grid code of a country depends on the past practices of its electricity sector, present regulatory and governing structures of its electricity sector, energy sources available and various legal, technical, and commercial aspects. Grid codes are comprehensive documents; its different sections have varying significance to different stakeholders. Some of the rules may be for promoting a competitive environment for generators whereas others may be critical for the operation/maintenance of generation plants.

It is essential that before interconnecting two grid systems, the respective grid codes of both countries are compared and reviewed to first understand the underlying principles of the individual systems and then harmonize the relevant rules to suit cross-border interconnection and trading. The respective Transmission System Operators (TSOs) of a planned regional grid interconnection should first establish a common framework for preparation and implementation of operating guidelines and procedures, maintenance schedules, exchange of data, dispute settlement, power exchanges, and electricity market mechanisms.

Figure 2. Grid Code Development and Maintenance Process Flow Chart



Source: Authors

The strategies and procedures for forming a grid code and its revision process are shown as a flow chart in Figure 2. Therefore, harmonization of the grid codes is an important pre-requisite for facilitating cross-border power trade. Harmonization in this context means adjustment of differences and inconsistencies among measurements, methods, procedures, schedules, specifications, or systems to make them uniform or mutually compatible. Compatibility is required for some types of interconnection. In the case of a synchronous interconnection, for instance, voltage, basic insulation strength, nominal frequency and protection schemes must match, whereas in the case of an asynchronous interconnection, the fault on one side is not passed on to the other, so the two sides worry less about each other. Nevertheless, the tripping of an HVDC terminal would itself constitute a disturbance in terms of loss of load or loss of supply.

Irrespective of the nature of interconnection, real-time communication through hotline, data transfer, and cooperation between the grid operators is necessary. Grid details must be shared and joint emergency response and recovery procedures from both grid operators must be ready. It should be emphasized however that the objective of harmonization is to arrive at a practical working arrangement for secure and reliable grid operation, which is feasible even without a uniform grid code.

2. APPROACH AND METHODOLOGY

The main objective of this report is to recommend a common ASEAN-wide grid code and to conduct a desk study on the technical gaps of national grid codes and regulations with respect to a potential ASEAN-wide grid code, for the following countries: Cambodia, Lao People's Democratic Republic (Lao PDR), Myanmar, Thailand, Vietnam, Indonesia, Malaysia and Philippines. Of these eight countries, five countries, namely, Cambodia, Lao PDR, Myanmar, Thailand and Vietnam, are part of the GMS. GMS member states have committed to establish the policy and institutional frameworks for advancing regional electricity trade. A draft GMS Regional Grid Code has been compiled through work carried out under the GMS framework, which is a key regulatory instrument to achieve the objective of facilitating increased multilateral trade. The Regional Power Trade Coordination Committee (RPTCC), which oversees the GMS stakeholder process on regional power trade, conducted several meetings with member countries to finalize the draft GMS grid code. The technical and institutional gaps of each national grid code against the draft GMS grid code are studied to provide solutions to address the gaps.

It should be noted that five of the ten ASEAN member states are thus in an advanced stage of finalizing the GMS Regional Grid Code and have taken steps to harmonize their national grid codes with the GMS Regional Grid Code for power trade. Hence, it is not practical to suggest an alternate ASEAN-wide common grid code which is substantially different from the existing proposed GMS Regional Grid Code. The authors believe that the GMS Regional Grid Code itself would constitute a reasonable basis for the development of an ASEAN-wide grid code. Hence, the gap analysis of the grid codes of Indonesia, Malaysia, and the Philippines with the GMS Regional Grid Code is relevant and necessary for establishing a common ASEAN-wide grid code.

This study recommends a practically feasible and economical approach for introducing an ASEAN-wide regional grid code to facilitate greater cross-border power trade. First, a harmonized bilateral model can be established to improve efficiency of bilateral trading by developing a set of standardized bilateral contracts. The technical standards of grid codes would be harmonized with the GMS Regional Grid Code to add more cross border interconnections [21]. Next, a secondary regional market model should be introduced to create a regional market for countries to use in addition to existing domestic markets. Finally, for countries that wish to do so, a primary trading model could be introduced which would replace the domestic market with a unified regional market.

The technical requirements for VRE integration within an ASEAN-wide regional code is included in the report. The technical requirement for VRE to contribute to maintaining power system stability and reliability at various phases of VRE integration is specified. It should be noted that stringent technical requirements will decrease the speed of development of VRE in a country, especially at the initial stages of VRE integration. Even though the regional VRE code does not replace the national grid codes, it will provide a common framework and minimum standards all national grid codes must meet. This also allows the flexibility for national grid codes to set country specific requirements.

2.1 SOURCES

The key sources consulted are listed in Table 1.

Table 1. Key Sources Consulted

Study Title	Month-Year	Conducted By	Funding Agency
Report on ASEAN Grid Code Comparison Review	October 2018	ASEAN Centre for Energy (ACE) Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ)	German Federal Ministry for Economic Cooperation and Development (BMZ)
Report on ASEAN Renewable Energy Grid Integration Review	April 2019	ACE; GIZ	BMZ
The Study on Power Network System Master Plan in Lao People's Democratic Republic	February 2020	Tokyo Electric Power Company (TEPCO); NIPPONKOEI	JICA
Harmonizing Power Systems in the Greater Mekong Subregion: Regulatory and Pricing Measures to Facilitate Trade	February 2020	Asian Development Bank (ADB)	ADB
Greater Mekong Subregion Energy Sector Assessment, Strategy, and Road Map	June 2016	ADB	ADB
Establishing Multilateral Power Trade in ASEAN	August 2019	International Energy Agency (IEA); Delphos International; Nord Pool Consulting; PJM; ACE	IEA
Scaling up variable renewable power: The role of Grid codes	2016	International Renewable Energy Agency (IRENA)	IRENA
ASEAN Renewable Energy Integration Analysis	October 2019	IEA	IEA
26th Regional Power Trade Coordination Committee Meeting (RPTCC-26) documents	November 26-27, 2019	RPTCC	ADB

3. EXISTING TECHNICAL FRAMEWORK AND GAP ANALYSIS

To recommend a common ASEAN-wide grid code, it is vital to assess the current status of each ASEAN member state's power system, grid code standards, transmission interconnections, and VRE integration. The power system structure and grid code details can indicate the organizational involvement, geographical benefits and issues, as well as the phase and pace of power system development in each country. The scope for economical and reliable interconnections among the member states are possible only by understanding their current interconnection level, future expansion plans and available voltage levels. In order to recommend the guidelines for connecting VRE into the system, each country's existing VRE penetration level, incorporated policies and technologies, growth rate and future development plans must be understood. These summaries and findings are the base for recommending a harmonized grid code for the ASEAN member states.

3.1 LAO PDR

3.1.1 POWER SYSTEM OVERVIEW

Lao's power system consists of two separate grids dedicated for domestic demand and for export (generator-to-system or G-S scheme). The Ministry of Energy and Mines (MEM) is primarily responsible for the power sector in the Lao PDR, with jurisdiction over energy policy, strategy, and management of the energy and the mining industries across the country. MEM oversees the activities of several state-owned enterprises (SOEs) involved in the energy sector: Électricité du Laos (EDL), EDL-Generation Public Company (EDL-Gen), and its subsidiary EDL-Gen Solar.

The Ministry of Planning and Investment and Ministry of Natural Resources and Environment also provide additional oversight to MEM. MEM underwent restructuring in September 2017 and currently consists of eight departments involved in policy and regulatory affairs. Beside the central government, provincial authorities support rural electrification through the operation of 85 mini-grids supplied by diesel generators, small hydropower, or other renewable sources, and assist with the preparation of regional power development plans (PDPs) [11]. EDL-Gen, a public company owned by EDL, assumed ownership of nearly all EDL generation assets following its formation in 2010. Together with EDL, both entities accounted for 813 MW of installed capacity and 2,849 GWh of generation in 2017. EDL-Gen is the main generator that serves the domestic market in the Lao PDR and, as of 2017, accounted for an installed capacity of 622 MW across 10 wholly owned projects, generating 2,610 GWh.

The Government of Lao PDR and Electricite due Laos (EDL) entered into a joint venture with China Southern Power Gridto form the EDL Transmission Company (EDL-T) on March 11, 2021. The agreement states that EDL-T will serve as the country's national power grid operator under the supervision of the Government of Lao PDR. It will invest, construct, and operate power grids (230 kilovolts and above), and implement grid interconnection projects between Lao PDR and its neighbors. It is still undetermined or unclear whether EDL-T will have the exclusive right to export power to neighboring countries or construct interconnections or whether EDL also has this right.

EDL-Gen is also actively developing non-hydro renewable energy projects through its subsidiary EDL-Gen Solar, established in 2015 to focus on developing solar energy projects in the country. In August 2017, EDL-Gen Solar commissioned two solar pilot projects totaling 10 MW in Vientiane region, and an additional 22 MW of solar capacity reached commercial operation in May 2018. The country has been successful in encouraging and attracting private investment and foreign direct investment (FDI) in power generation projects, and, as of the end of 2017, IPPs accounted for around 6.3 (GW) (88%) of total installed capacity in the country. IPP projects between 5 MW and 100 MW must be approved by the government upon consultation with stakeholders, while projects greater than 100 MW required to be approved by the country's National Assembly.

Lao Holding State Enterprise (LHSE) is responsible for the state's financial holdings in hydropower projects built by foreign and private investors. These projects are focused more on cross-border power exports than on serving the domestic market and include the government's 25% share in Nam Theun 2 and Nam Ngiep 1 hydropower projects, 20% share in the Hongsa lignite mine mouth power project, and 24% share in Xe Pian-Xe Namnoy hydropower projects, among others.

3.1.2 APPLICABLE GRID CODE DOCUMENTS

The Electricity Law of 1997, revised in 2008, 2011, and 2018, provides the legal framework underpinning the Lao PDR's power sector and establishes the principles, regulations, and measures that govern activities therein. The most recent revision to the Electricity Law requires the preparation of a 10-year power development strategy to set out the road map for the power sector [11]. The National Policy on Sustainable Hydropower Development in Lao PDR, reflecting the central role that hydropower plays in the power sector and its broader economic contribution, was implemented in 2015.

The current grid code of Lao PDR was formulated in 2013. Some of the salient features of the grid code and grid operation are as follows:

- The allowable range of grid frequency in normal state is between 49.5Hz and 50.5Hz.
- The domestic HV grid in Laos is synchronized with Thailand's grid and controlled in large part by Thailand's EGAT.[1] The domestic Lao PDR grid is linked with the Thai grid through nine 115 kV AC international tie-lines as well as three 500 kV lines, two 230 kV lines, and others. Of these, the grid-to-grid connections are all at 115 kV. The system capacity of the Thai grid is 30 times larger than that of the Lao PDR grid, which makes the Lao PDR grid relatively stable from a frequency aspect, although autonomous frequency and tie-line power flow control is not performed. For power stations on the domestic grid, instructions to the power stations are issued by EDL-NCC according to requests from EGAT by telephone; LFC and AGC are not

[1] See "The Study on Power Network System Master Plan in Lao People's Democratic Republic", JICA. 2020. Section 19.1.2 and 19.4.4.

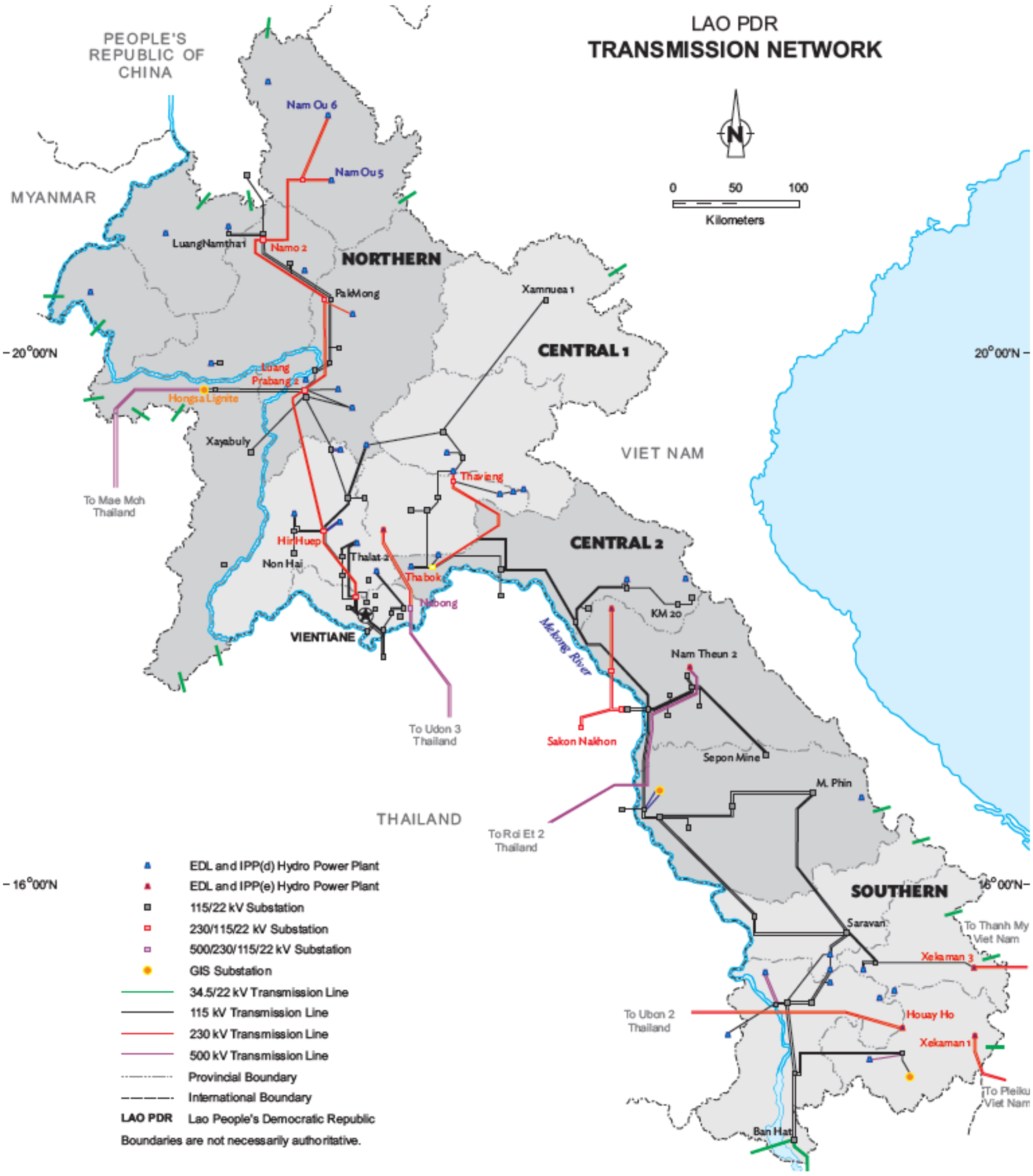
applied at all. Governor-free operation (frequency sensitive mode operation), according to an interview with the NCC, is rarely implemented, except for some large capacity hydropower generators like the Nam Ngum hydropower plant. There is no mechanism for under-frequency load shedding (UFLS), and a manual load shedding (MLS) scheme is used in emergency situations.

- For generation exported to Thailand through dedicated HV lines (230 kV and 500 kV), supply and demand balance and frequency control are implemented directly by EGAT.
- Normal State: below 90% of continuous ratings (thermal limit).
- Security and reliability of the grid shall be based on the single outage contingency (N-1) criterion.
- Allowable range in normal state = Nominal Voltage ±5%.
- Allowable range in emergency state = Nominal Voltage ±10%.

3.1.3 TRANSMISSION INTERCONNECTION

The Lao PDR's transmission network is operated by EDL and comprises four grid regions across the north, central 1, central 2, and south. The country's central location within the GMS and vast hydropower potential allows it to supply electricity to sizable neighboring markets such as Thailand and Vietnam and to a lesser extent, also to Cambodia and Myanmar [11]. As of 2017, the national high-voltage transmission network consisted of 11,301 kilometers (km), predominantly 115 kV and 230 kV lines, with only 462 km rated at 500 kV. Three 500 kV lines and two 230 kV lines are dedicated for export to Thailand. Two additional 230 kV lines are for export to Viet Nam. Eleven 115 kV lines facilitate power exchange between Cambodia (1), the PRC (1), and Thailand (9). Nineteen medium-voltage (22 kV and 35 kV) lines are dedicated for import or export with all five neighbors: Cambodia (1), Myanmar (1), the PRC (3), Thailand (7), and Viet Nam (7).

Figure 3. Lao PDR HV Grid (2017)



Source: "Lao People's Democratic Republic Energy Sector Assessment, Strategy, and Road Map." ADB, November 2019.

While most high-voltage transmission lines are owned by EDL, export-oriented IPP projects use dedicated transmission lines to interconnect directly with neighboring grids. The country currently has 32–33 interconnections with its neighbors, including Cambodia (2), Myanmar (1), the PRC (4), Thailand (17), and Viet Nam (7). MEM has also signed an MOU with Myanmar's Ministry of Electricity and Energy with a view to securing exports for 300–500 MW. Thailand has continued to be the main off-taker of exported power. Exports to Vietnam have begun only recently with around 1 GW at present and MEM expecting a further 1.5 GW by 2025.

In September 2017, the Lao PDR signed an energy purchase and wheeling agreement with Malaysia and Thailand, representing the first multilateral energy exchange or trade in the ASEAN and facilitating multilateral cross-border power trade beyond the Lao PDR's immediate neighbors. Under the 2-year agreement, the Lao PDR sold up to 100 MW of electricity to Malaysia via Thailand's power transmission grid, beginning on 1 January 2018. The agreement, previously referred to as the LTM-PIP, was recently extended and now includes Singapore as well (the LTMS-PIP).

The country has plans to install 25 more transmission lines and associated substations by 2025. Plans include nine new cross-border high-voltage lines, six of which will be owned by EDL, including the first high-voltage transmission line for export to Myanmar[2].

3.1.4 VRE INTEGRATION

The Lao PDR is also endowed with significant resource potential for non-hydro renewables that includes solar, biomass and wind. Through its Renewable Energy Development Strategy, 2011–2025, the country is seeking to promote non-large hydropower renewable resources to reach a 30% share of the country's total energy demand by 2025 [11]. Conditions for solar power are less favorable in Lao PDR than most other Association of Southeast Asian Nations (ASEAN) member countries due to the mountainous and forested terrain. Although the southern part of Lao PDR is more favorable for solar, the country's topography is a limiting factor for the development of utility-scale solar projects.

The development of solar photovoltaic (PV) projects has amounted to 32 MW to-date, following the commissioning of three government-led pilot projects in Vientiane in February 2017 (3 MW), August 2017 (7 MW), and May 2018 (22 MW). EDL-Gen Solar has longer-term ambitions to develop an additional 100 MW of solar projects in the Lao PDR for domestic consumption and 500 MW at a later stage to provide exports to Thailand.

A further 68 MW of utility-scale solar PV projects was planned by 2020 but scaling of utility-scale solar generation in the Lao PDR will require institutional and financial resources to support grid integration studies, site assessments, and cost–benefit analyses, which are traditionally integral to decisions to make such investments. Given the Lao PDR's geography, there are inherent practical challenges to developing conventional ground-mounted solar in the country. Therefore, installing floating solar on reservoirs used for hydropower generation and irrigation dams is being considered by the ADB.

Wind speeds in the Lao PDR are typically low, thus limiting the commercial application of wind power. Pre-feasibility studies of wind potential have thus far only been undertaken in two districts in Savannakhet Province (64 MW) and one district of Champasak Province (50 MW). Currently, there are no operational wind projects in the Lao PDR despite the 73 MW target via the Renewable Energy Development Strategy, 2011–2025.

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[2] Even before the coup in Myanmar, this project, which would interconnect at Kengtung, Myanmar, appeared to have limited support within MOEE, the main Myanmar power sectoral institution.

Figure 4. Renewable Energy Targets for Lao PDR

Source	Target 2010–2015 (cumulative MW)	Target 2016–2020 (cumulative MW)	Target 2021–2025 (cumulative MW)
Small hydro	80	134	400
Solar	22	36	33
Wind	6	12	73
Biomass	13	24	58
Biogas	10	19	51
Municipal solid waste	9	17	36
	140	242	651

Lao PDR = Lao People's Democratic Republic, MW = megawatt.

Source: Government of the Lao PDR, Ministry of Energy and Mines, Institute of Renewable Energy Promotion. 2016. *Renewable Energy Data in Lao PDR.* Paper prepared for the East and Southeast Asia Renewable Energy Statistic Training Workshop. Bangkok. 12–14 December.

3.1.5 TECHNICAL GAP ANALYSIS

The existing framework of the Lao's grid code has some key drawbacks, as listed below.

1. Lao's grid is synchronized with EGAT through 115kV transmission lines, but autonomous frequency and tie-line power flow control is not performed.

2. Although the instructions to the generating power stations are issued by EDL-NCC according to requests from EGAT by telephone, LFC and AGC are not applied at all. Governor-free operation (frequency sensitive mode operation) is rarely implemented, except for some large capacity hydropower generators like the Nam Ngum hydropower plant.

3. There is no mechanism for Under-Frequency Load Shedding (UFLS), and a Manual Load Shedding (MLS) scheme is used in emergency situations.

4. It is not clear what the allowable range of power flow on EDL grid is when the grid is in an emergency state.

5. The allowable range of power flow on international tie-lines is not clear.

6. Power flow management and monitoring are handled through instructions by telephone. Even in emergency situations, there is no device that automatically controls the power flow. These gaps are likely to lead to grid failures.

7. There are operational issues concerning overvoltage during periods of low demand. Disconnection of one line of the double-circuit transmission line is one of the countermeasures implemented to suppress the voltage. This operational measure is commonly used worldwide, but it is not preferable in the Lao grid because it reduces the transmission capacity and stability.

8. Phase angle stability is not clear in the Lao's grid code.

9. Although PSSs (Power System Stabilizers) are partly installed in the generators, they are not appropriately understood at the NCC and the tuning of parameters of PSSs is not properly implemented.

The JICA report (see Table 1) included a gap analysis of the Lao PDR grid code. When the JICA report was completed, the draft GMS grid code had not yet been released. The JICA report therefore compared the Lao PDR grid code with the EU grid code, which also has a harmonized grid code for transmission networks from different countries within the EU. Specific clauses were aligned across the two grid codes, and the level of compliance was assessed. The result of the study is presented in the following figures. As can be seen, compliance levels are low (gaps are high) for most items.

Figure 5. Comparison of the EU and Lao PDR Grid Codes for Generation Code

A network code on requirements for grid connection of generators	Rough estimation of achievement in Lao Code		
I. Requirements	**Yes**	**No**	**Rate**
1. Frequency Stability	9	31	22.5%
2. Voltage stability:	6	22	21.4%
3. Fast Fault Current Supply	0	4	0.0%
4. Robustness:	0	18	0.0%
5. System Restoration:	3	17	15.0%
6. General system management requirements:	9	41	18.0%
II. Notification	**Yes**	**No**	**Rate**
1. Notification Method	0	3	0.0%
2. Procedure			
2.1 Energisation Operation Notification (EON)	0	5	0.0%
2.2 Interim Operation Notification (ION)	1	15	6.3%
2.3 Final Operational Notification (FON)	6	0	100.0%
2.4 Limited Operational Notification (LON)	0	7	0.0%
2.5 Decommissioning	0	3	0.0%
III. Compliance	**Yes**	**No**	**Rate**
1. Compliance monitoring	0	12	0.0%
2. Compliance testing	12	8	60.0%
3. Compliance simulation	7	11	38.9%
IV. Derogation	**Yes**	**No**	**Rate**
1. Power to grant derogations	0	1	0.0%
2. General provisions	0	3	0.0%
3. Request for a derogation by a power-generating facility owner	0	12	0.0%
4. Request for a derogation by a relevant system operator or relevant TSO	0	11	0.0%
5. Register of derogations from the requirements of this Regulation	0	2	0.0%
6. Monitoring of derogations	0	3	0.0%

Figure 6. Comparison of the EU and Lao PDR Grid Codes for Power System Operation Code

Guideline on electricity transmission system operation	Rough estimation of achievement in Lao Code		
I. Operational Security (OS)	**Yes**	**No**	**Rate**
1. Operational Security Requirements - Monitoring of system state, remedial actions, etc.	16	19	45.7%
2. Data Exchange - b/w other TSOs, DSOs, Facility owers, etc	13	8	61.9%
3. Operational Test - Purpose, responsibility, process, etc	2	0	100.0%
4. Training - for system operation sector staff, shift engineers, certification system, etc	0	9	0.0%
II. Operational Planning & Scheduling (OPS)	**Yes**	**No**	**Rate**
1. Data for Operational Security Analysis in Operational Planning - Common model for analysis	8	8	50.0%
2. Operational Seculity Analysis	5	1	83.3%
3. Outage Coordination	7	9	43.8%
4. Adequacy	3	3	50.0%
5. Ancillary Services	2	2	50.0%
6. Scheduling	5	5	50.0%
III. Load-Frequency Control and Reserves (LFCR)	**Yes**	**No**	**Rate**
1. Frequency Quality - criteria for evaluation	4	13	23.5%
2. Load-Frequency Control Structure - Activation process, resposibility, etc.	8	10	44.4%
3. Frequency Containment Reserves (FCR) = Primary reserves	7	6	53.8%
4. Frequency Restoration Reserves (FRR) = Secondary reserves	3	8	27.3%
5. Replacement Reserves (RR) = Tertiary reserves	3	6	33.3%
6. Exchange and Sharing of Reserves	0	12	0.0%
7. Time Control Process - Adjustment of electrical time deviation to the standard time	0	1	0.0%

Figure 7. Comparison of the EU and Lao PDR grid codes for Network Code

ENTSO-E Working Draft Network Code on Emergency and Restoration	Rough estimation of achievement in Lao Code		
IV. System Defence Plan	**Yes**	**No**	**Rate**
1. General Principles	0	8	0.0%
2. Measures of the System Defence Plan - only focused on under-frequency management	6	17	26.1%
V. Restoration Plan	**Yes**	**No**	**Rate**
1. General Principles	1	6	14.3%
2. Re-Energisation	2	10	16.7%
3. Frequency Management	0	26	0.0%
4. Resynchronisation	2	18	10.0%

In 2020, under the USAID Clean Power Asia program, and in coordination with EDL, the Hawaii Natural Energy Institute developed proposed Distributed Solar Photovoltaic Generating Facility Interconnection Standards and in 2021 developed proposed Inverter-based Generating Facility Transmission Interconnection Standards. Implementation of the proposed standards would address gaps in Lao PDR's existing grid code with regards to connection and operating codes relevant to inverter-based VRE generation.

3.2 MYANMAR

3.2.1 POWER SYSTEM OVERVIEW

The Ministry of Electricity and Energy (MOEE), formed by the merger in 2016 of the Ministry of Energy and the Ministry of Electric Power, is the chief energy sectoral entity. MOEE is split between electricity and energy sides. The electricity side is responsible for planning, operation and commercial aspects of the electric power system. The energy side focuses on production, import/export, and distribution of oil and gas and related products. Private participation in generation is *via* IPPs and joint ventures with MOEE, and there are several small private distribution company concessions.

Myanmar's on-grid power system is dominated by hydroelectric and gas-fired generating capacity. A small amount of coal-fired capacity and small diesel gensets, plus a single 40 MW solar PV project, makes up the balance. Hydro projects (and most remaining hydro resources) are located mainly in the north of the country, while most demand is located farther south, especially in the Yangon area. Gas-fired capacity is fueled by domestic natural gas but severely constrained by lack of usable gas supply.

The generation capacity expansion plans have historically focused on hydropower and coal-fired plants, although LNG-to-power projects became the focus on the thermal side due to domestic and international political opposition to coal-fired plants. However, Myanmar faced delays implementing planned LNG-to-power projects, MOEE more recently has shifted its focus to solar PV to bring capacity online quickly. MOEE announced a tender process for 1,060 MW in May 2020 and awarded the concessions to bidders (nearly all Chinese) in September 2020.

3.2.2 APPLICABLE GRID CODE DOCUMENTS

Myanmar currently lacks a formal grid code but has a set of technical standards and documentation referred by MOEE that provide guidelines for grid operations.

Draft Grid Code

An International Development Agency has assisted MOEE in drafting a grid code for synchronous generators (hydro and thermal power plants). This draft grid code is currently under review for approval from the cabinet so that it can be enacted as law. Although the document has not been formally adopted, MOEE and the local IPPs often refer to this draft grid code for their planning, connection, and operation.

National Guidelines and specification for Secondary Systems and Protection

MOEE has well-documented guidelines, standards, and specifications for Secondary Systems and Protection of HV substations (230kV and 132kV) based on international standards (such as IEEE, IEC, and ANSI). MOEE also have preferred vendors/manufacturers for protection switchgear. These guidelines usually accompany the tender documents for the Engineering, Procurement, Installation and Commissioning of projects (EPIC).

Proxy International Standards

For all other engineering design/manufacture/procurement/construction/commissioning activities that are not covered in the National Guidelines and specification for Secondary Systems and Protection, MOEE recommends the vendor/consultant to refer to any reputable International standard as applicable. However, no specific international standards are mentioned explicitly for a particular issue. Some international standards cannot be directly applied to Myanmar conditions because the requirements must be tailored and specific for projects within Myanmar.

For solar projects, MOEE accepts the following international standards for technical guidelines regarding connection and operation:

i. American National Standards Institute (ANSI)

ii. British Standards Institution (BSI)
iii. German Standardization Institute (DIN)
iv. World Bank Environmental, Health, and Safety Guidelines (EHS)
v. International Electrotechnical Commission (IEC)
vi. Institute of Electrical Engineers (IEE)
vii. Institute of Electrical and Electronics Engineers (IEEE)
viii. Institution of Engineering and Technology in the UK (IETE)
ix. IFC Environmental and Social Performance Standards (PS)
x. International Standards Organization (ISO)
xi. Japanese Industrial Standards (JIS)
xii. Manufacturer's Standardization Society (MSS)
xiii. National Electrical Manufacturers Association (NEMA)
xiv. National Fire Protection Association (NFPA)

3.2.3 TRANSMISSION INTERCONNECTION

The Department of Electric Power Transmission System Control, an entity under MOEE, develops and implements the transmission network (66 kV, 132 kV, 230 kV, and 500 kV) including its operation and maintenance. Currently, several 500 kV transmission lines are under construction that will connect the majority of the country's generation facilities, predominately located in the north, with the main load centers in the south [15]. The government also plans to construct additional 230 kV, 132 kV, and 66 kV transmission lines.

Cross-border connections have been established to export power from the 600 MW Shweli-1 Hydropower Plant and from the Dapein Hydropower Plant to China.

Most studies of cross-border power connections in the GMS assume large growth in power exports from Myanmar to China, which would require significantly more transmission capacity. However, authorities have made no definite decision on specific routes or the schedule of construction for these lines. Myanmar could expand import/export capacity with transmission system reinforcement projects at the existing facilities under operation with China, namely Shweli and Tapein. There have also been other bilateral Memoranda of Understanding (MOU) agreed with both China and Lao PDR. Myanmar also signed an MOU (which expired in 2010) with Thailand for power exports of 1,500 MW initially, increasing to 3,000 MW. Likewise, any plans to eventually trade power with Thailand would also require expanded transmission capacity.

3.2.4 VRE INTEGRATION

In 2014, the Government passed a new electricity law. However, the law does not yet include implementing rules and detailed guidelines. As a result, the regulatory environment is ambiguous and can be challenging to navigate. Myanmar does not yet have standardized practices for joint ventures and PPAs, which leads to time-consuming case-by-case negotiations.

The current level of VRE penetration in Myanmar is low. Mini hydro and solar account for just 0.11% of installed capacity [14]. There is an increased emphasis in renewables, particularly solar, to add power generation capacity. The government has recently launched procurement processes for several large solar plants, as indicated in Table 2. The Government's National Electrification Plan aims to connect 2 million households from 2015 to 2020 and an additional 5.2 million households in the 10 years to 2030, by solar home systems (SHSs) and mini-grids [15].

Table 2. Recent Renewable Energy Developments in Myanmar

Sr	Project Name	MW	Resource	PPA Status
1	Chaung Thar	30	Wind	
2	Shwemyo (Thinkhaypa)	10	Solar	
3	Thapyaysan	100	Solar	
6	Nabuai	150	Solar	Phase 1 passed, 2 ongoing
7	Wantwin	150	Solar	Phase 1 passed, 2 ongoing
8	Minbu Solar	170	Solar	Ph-1 operational, 2 und-con

Source: RPTCC-26, Myanmar country presentation.

There have been some initial steps taken to create the technical framework to integrate on-grid solar plants. Current MOEE guidelines on operating conditions for generation plants, formulated with technical assistance from JICA, are based on conventional generating systems like hydropower or thermal plants. These guidelines specify plant operating parameters with relation to system conditions in terms of the voltage range, frequency range, and the system short circuit strength of the network. As part of a technical assistance from the New Zealand Renewable Energy Programme in Myanmar, AECOM conducted grid impact studies for on-grid solar plants based on the existing operating parameters specified and made recommendations to MOEE regarding the technical requirements to connect solar plants to the grids, including technical specifications for inverters and other key solar plant equipment.

3.2.5 TECHNICAL GAP ANALYSIS

Integrating large scale solar plants directly to the transmission network without an appropriate technical framework will complicate and negatively impact grid operations. There are examples from elsewhere of blackouts caused by cascading failures of VRE plants due to a lack of proper grid codes and technical regulations. The grid code for the network should deal with several areas: generation, transmission, and distribution. The technical limits associated with grid operations, namely regarding frequency, voltage, active power, reactive power and the ranges of each, during which the plants should be connected and disconnected are key parts of the grid code requirements. In the context of Myanmar, it is also important to deal with grid access and centralized and decentralized generation, including micro-grids.

In Myanmar, the MOEE accepts international standards such as IEEE and IEC for integration of grid-connected solar plants; this has been explicitly mentioned in the ongoing tender processes for solar power projects. It is important to note, however, that some of the standards may not be directly applicable in Myanmar's context. For example, the technical connection requirements in IEEE 1547 for integration of solar plants are based on the US power system. The frequency range (60Hz), the voltage range, and ride through criteria values are formulated based on the US power grid requirements. Therefore, Inverters used for integrating solar plants to the grid which comply with IEEE 1547 cannot be used in Myanmar's network.

The current Draft Grid Code (which is expected to be enacted into law as the National Grid Code and which already sets informal standards) does not have any sections specific to grid-connected solar plants. The generation from solar PV plants varies by atmospheric conditions such as solar irradiance or temperature, sometimes by as much as 70%, within very short time frames (2 to 10 minutes). These rapid changes in generation can also happen several times a day. Technical regulations and standards are necessary to enable grid operators to direct these plants to control their generation (ramping up or down or even curtailing) when necessary, for maintaining stable and secure grid operations. It is important for the MOEE to explicitly define these standards now for long-term planning so that grid operations remain stable even as VRE penetration increases in Myanmar.

3.3 THAILAND

3.3.1 POWER SYSTEM OVERVIEW

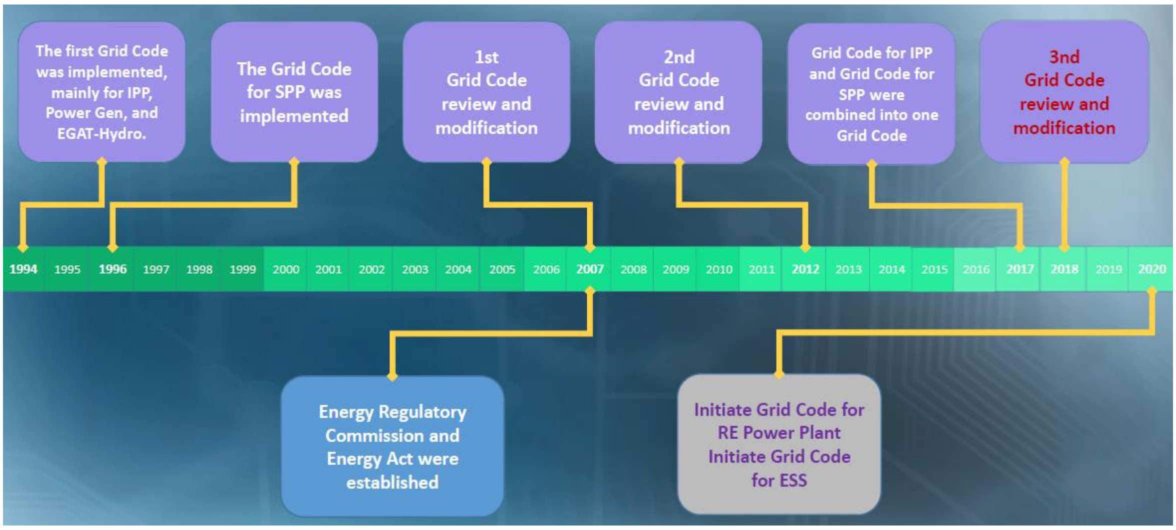
The power sector in Thailand is governed by the Ministry of Energy (MoE) and regulated by the Electricity Regulatory Commission (ERC). The electricity sector is partially unbundled and organized as a single buyer system. The state-owned Electricity Generating Authority of Thailand (EGAT) owns and operates the transmission system. EGAT is also responsible for system operations and securing power supply, which it does through a combination of its own generation, PPAs with IPPs in Thailand, and imports from neighboring countries. EGAT sells wholesale power to two other state-owned entities, the Provincial Electric Authority (PEA) and Metropolitan Electric Authority (MEA), which own and operate the distribution grids.

3.3.2 APPLICABLE GRID CODE DOCUMENTS

The grid code in Thailand was first implemented in 1994 and has subsequently undergone three revisions, most recently in 2019. The structure of the current grid code is:

i. Connection Code – provides rules on connecting generation resources to the grid, both distribution level and EGAT grid;
ii. Operation Code – covers operational parameters for overall transmission and distribution systems, and particularly for IPPs; and
iii. Service Code – defines qualifications of system users and outlines their duties and responsibilities and also covers the necessary forms, regulations, and fees.

Figure 8. Timeline of Grid Code Implementation and Updates in Thailand



Source: RPTCC 27 – Thailand Country Presentation

As illustrated in Figure 8, additional efforts are currently underway to revise the grid code to incorporate VRE, provide appropriate guidelines for battery storage and other new technologies, and define rules and operations of the DRCC including exchange of data and information with load aggregators.

3.3.3 TRANSMISSION INTERCONNECTION

The high voltage transmission networks (500 kV and 230 kV) are owned and operated by EGAT [6]. The primary 500 kV transmission lines carry bulk electricity from generation sources located in the north, north-east, east and west to the major demand centers in Bangkok and the metropolitan and central areas. The 230 kV lines have the highest aggregate transformer capacity, whereas the 500 kV transmission circuits represent around 30% of total transformer capacity. In addition, EGAT also operates 115 kV transmission lines as well as a small number of 69 kV lines.

Thailand imports a significant amount of electricity from Lao PDR via 230 kV and 500 kV transmission lines, from both hydropower and coal-fired power plants contracted under power purchase agreements. Moreover, there is a high-voltage direct current (HVDC) connection with Malaysia in the southern part of Thailand with a capacity of 300 MW. This HVDC interconnection not only provides energy exchanges but has also been set to automatically provide response in the events of low frequency (from 49.75 Hz). Under the Laos-Thailand-Malaysia Power Integration Project (LTMS-PIP, Malaysia has also been importing 100 MW from Lao PDR, wheeled through Thailand's interconnections. The agreement was expanded to 300 MW for sales to Malaysia and extended the project to Singapore for 100 MW of sales.

In general, Thailand's transmission grid appears to be relatively well-developed, robust, and reliable. Multiple transmission circuits supply the major load centers in different regions, particularly in the central and metropolitan areas. The southern region of Thailand is perhaps the most challenging region for maintaining reliable system operation and stability, owing largely to its partly electrically isolated geography, which only allows for radial connections with the central regions without the possibility to connect to other regions. The transmission lines connecting with the central regions play a significant role in maintaining system stability and security.

3.3.4 VRE INTEGRATION

Thailand has among the highest levels of VRE penetration in ASEAN and is a leader in the development of grid infrastructure, advanced operational practices, and deployment of other flexibility options. In 2019, renewable energy contributed about 20% of generation, which was predominantly hydropower [23]. The annual energy penetration of VRE in Thailand is around 4%, and VRE generation is becoming noticeable to system operators. Thailand is establishing a Renewable Energy Control Centre (RECC) to enhance visibility and improve control of VRE in Thailand.

Establishing the RECC will be important to support Thailand's planned increases in VRE growth. The main target of the Alternative Energy Development Plan (AEDP) is to increase the portion of renewable energy generation from 20% to 46% of the total power requirement, to almost 35.8 GW by 2037. The government set a target in the Power Development Plan (PDP) 2018 to increase VRE capacity, particularly solar PV and wind, to almost 35.8 GW by 2037. The government set a target in Alternative Energy Development Plan (AEDP) 2018 to increase VRE capacity, particularly solar PV (9 GW) and wind (1.485 GW), to almost 10 GW by 2037, around 30% of total energy [6].

Thailand's transmission grid, unlike that of most developing countries, also has the potential to be an important flexibility resource as the share of solar and wind generation increases. However, the extent to which the transmission grid will be useful to support VRE integration will also depend on the region, each of which has different resources and infrastructure, and future generation and transmission plans to achieve cost-effectiveness while maintaining system reliability.

3.3.5 TECHNICAL GAP ANALYSIS

ACE conducted a review of the grid codes in Thailand and compiled recommendations to align them with international best practices. The ACE study provided a summary of the requirements for generators under the EGAT, MEA, and PEA grid codes, as shown in Table 3. It is important to note that this study was conducted based on the 2012 EGAT grid code and not the most recent update in the 2019 version.

The previous EGAT grid code was aimed at conventional generation with no mention of renewable generators. The frequency and voltage control requirements do not address the further implications due to VRE installations. The EGAT requirements from 2008 contained a section on requirements for wind turbines [1]. The section exempted wind turbines from frequency control duties, required them to be controllable by the operator, and set specific voltage control requirements to the Automatic Voltage Regulator (AVR) that differed from the standard values for conventional generators. However, these requirements were not included in the 2012 EGAT grid code and hence are no longer applicable.

Table 3. Requirements for Generators under Different Grid Codes in Thailand[3]

Requirements for Generators			
Characteristic	**EGAT Grid Code**	**PEA Interconnection Code**	**MEA Interconnection Code**
Applicable to	Generators connected to EGAT transmission grid (≥ 69 kV)	Generators connected to PEA distribution grid (230V – 115 kV)	Generators connected to MEA distribution grid (230V – 115 kV)
Permissible voltage range in the grid	±5% Vn regular ±10% Vn emergency	±5% Vn regular (MV + HV) ±10% Vn regular (LV) ±10% Vn emergency	*±3 % Vn regular (115 kV)* *+7/-3% Vn emerg. (115 kV)* *-2 %/- 9 % Vn regular (MV)* *+9/-2% Vn emerg. (MV)**
Frequency range for generators	49.5 – 50.5 Hz full output 47.0 – 52.0 Hz online	47.0 – 52.0 Hz	49.0 – 51.0 Hz (PV/VSPP) 47.0 – 52.0 Hz
Voltage range for generators	*0.9 – 1.1 p.u.**	0.9 – 1.1 p.u. unlimited 0.5 – 0.9 p.u. for 2 s 1.1 – 1.2 p.u. for 1 s	
Over-frequency behaviour	Droop control, over-frequency sensitivity	Trip immediately (VSPP), others must comply with EGAT grid code	Trip immediately (VSPP), adjustable trip setting
Underfrequency behaviour	Stay connected, output reduction allowed		
Active power control	AGC connection and governor (droop control) required	Remote control required for > 1 MW and all HV connected units	?
Power Factor	*0.85 leading* *0.85 lagging**	0.85 leading + lagging (synchronous) 0.9 leading + lagging (inverter) 0.95 leading + lagging (inverter connected to LV)	
Voltage control	Required, remote controllability required *AVR for wind turbines***	Q(U) characteristic selectable by operator	?
Fault behaviour / LVRT	*625 ms at 15% Vn for wind turbines***	150 ms for generators > 500 kW connected to MV and above	-
Flicker	Pst = 0.8 and Plt = 0.6 for 115 kV and above Pst = 1.0 and Plt = 0.8 for below 115 kV	-	IEC 61000-3-3 (2008)
Total Harmonic Distortion	2.45% for 69 kV 1.5% for 115 kV and above	Specified (probably 5%), lacking from English translation	5%
SCADA connection	Required, includes signal list	Required for > 1 MW and all HV connected units, includes signal list	?
Penetration limit	-	15% of DT load for LV 75% of transf. load MV 120/230 MW per circuit for single/double 115 kV	15% of DT load for LV and MV
Simulation model	IEEE block diagram required for thermal and Closed-Cycle Gas Turbine (CCGT) plants, detailed specifications	-	?

Source: "Report on ASEAN Grid Code Comparison Review", ASEAN Centre for Energy. [4]

According to the ACE study, the EGAT grid code lacked defined requirements for behavior outside of the normal voltage range which could be adapted from the PEA/MEA codes. The over frequency control to below 52 Hz was mentioned but lacked specifications. The PEA grid code was the newest and most advanced of the three grid code documents considered in the study and was found to be generally in line with international standards. It addressed all necessary issues in sufficient detail and even included an LVRT (Low Voltage Ride Through) requirement for units larger than 500 kW.

The Connection Code from the 2019 EGAT grid code appears to be complete and appropriate. It specifies Connection Conditions for 4 categories: 1) Power producers with PPA > 90MW, 2) Power

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[3] "LVRT" in the figure refers to Low Voltage Ride Through, that is, the ability of a project/inverter to avoid automatic disconnection when there are transient low voltage conditions on the grid, which could otherwise damage the project/inverter.

[4] Hz – Hertz, Vn – neutral voltage, p.u. – per unit, AVR – automatic voltage regulation, Pst – flicker short term perceptibility, Plt – flicker long term perceptibility, ms – milliseconds, IEC – International Electrotechnical Commission, IEEE – Institute for Electrical and Electronics Engineers, Pv – solar photovoltaics, VSPP – very small power producer, MV – medium voltage, and LV – low voltage

producers with PPA < 90 MW, 3) Third Party Access (TPA) and 4) Other Type of Power Generators. There is a brief description about Connection Conditions for "Hydro Floating Solar".

There have been some updates in the 2019 EGAT grid codes from the prior version as shown in Table 3.

- The allowed frequency range for generators to remain online has been narrowed from 47.0 – 52.0 Hz () to 49.9 – 51.1 Hz for under one minute and 48.0 – 51.0 Hz thereafter.
- The allowed voltage range is 0.85 – 1.30 for under 10 seconds and 0.9 – 1.15 thereafter.
- Power factor has been updated to 0.9 lagging and 0.9 leading.
- Total Harmonic Distortion is set to 3% for systems at 69 kV or higher voltages.

The Thai grid codes evaluated in the ACE study lacked clearly defined application and connection processes, which could become a barrier to renewable energy development. The revised 2019 grid codes address some of these gaps with some requirements specifically for VRE, including data requirements in the Connection Code and requirements to submit 15-min generation plans for solar and wind generators in the Operation Code.

3.4 CAMBODIA

3.4.1 POWER SYSTEM OVERVIEW

Cambodia's power sector is governed by the Ministry of Mines and Energy (MME), through the Department of Energy Development (energy and electricity planning), the Department of Energy Technology (technical standards, non-hydro renewables, and energy efficiency), and the Hydropower Department. The Ministry formulates energy policies and strategies, power development plans, and establishes technical and environmental standards. The Electricity Authority of Cambodia (EAC) is the industry regulator, responsible for issuing licenses and regulations, reviewing and approving tariffs, and other activities concerning oversight of the sector. Electric power supplied throughout the country is sourced from three different types of licensees including the state-owned Électricité du Cambodge (EDC), IPPs, and consolidated licensees including Rural Energy Enterprises (REEs).

Hydropower is the dominant source of electricity in Cambodia, comprising 60% of installed capacity and 46% of generation in 2019, followed by coal (38% of capacity and 22% of generation). The balance is sourced mostly from imports and fuel oil plants, with only a small share of generation supplied by non-hydro renewables. Thermal power plants operating on imported diesel provide a significant portion of generation, making the electricity tariff very volatile [9]. Despite recent improvements in the energy sector, the electrification rate in Cambodia remains low. Nearly 5 million Cambodians have no access to grid electricity and are reliant on car batteries, wood, and other traditional fuels for energy [8]. The major source of power generation is diesel and heavy fuel oil (HFO).

3.4.2 APPLICABLE GRID CODE DOCUMENTS

To prepare a governing framework for the electric power supply and services throughout the country, the Law on Electricity was adopted by the National Assembly in 2001 [8]. This law covers all activities related to the supply, provision of services and use of electricity, and other associated

activities of the power sector. Subsequent regulations, decrees, and other legal documents pertaining to the power sector in Cambodia are listed in

Table 4.

Table 4. Important Legal Documents in Cambodia's Electricity Sector

No.	Name of Standard Documents	Promulgated by	Date Promulgated
1	Electricity Law of the Kingdom of Cambodia	The King	February 2, 2001
	Amendment of Article 9 of the Electricity Law of the Kingdom of Cambodia		June 22, 2007
	Amendment of Articles 3, 4, 5, 26, 27, 28, 42, 74, of the Electricity Law of the Kingdom of Cambodia		May 18, 2015
2	Sub-Decree on the Rate of the Maximum License Fees applicable to Electric Power Service Providers in the Kingdom of Cambodia	Royal Government	December 27, 2001
3	Procedures for Issuing, Revising, Suspending, Revoking, or Denying Licenses	Electricity Authority of Cambodia	September 14, 2001
	Revision 1		December 12, 2002
	Revision 2		March 16, 2004
4	Regulations on General Conditions of supply of Electricity in the Kingdom of Cambodia	Electricity Authority of Cambodia	January 17, 2003
	Revision 1		December 17, 2004
	Version 2		March 15, 2016
5	Regulatory Treatment of Extension of Transmission and Distribution Grid in the Kingdom of Cambodia	Electricity Authority of Cambodia	October 28, 2003
6	Regulations on Overall Performance Standards for Electricity Suppliers in the Kingdom of Cambodia	Electricity Authority of Cambodia	April 2, 2004
7	Procedure for Filing Complaint to EAC and for Resolution of Complaint by EAC	Electricity Authority of Cambodia	April 2, 2004
8	General Requirements of Electric Power Technical Standards of the Kingdom of Cambodia	Ministry of Industry, Mines and Energy	July 16, 2004
	First Amendment		August 9, 2007
9	Sub-Decree on Creation of Rural Electricity Fund of the Kingdom of Cambodia	The King	December 4, 2004
10	Sub-Decree on Principles for Determining the Reasonable Cost in Electricity Business	Royal Government	April 8, 2005
11	Prokas on Principles and Conditions for issuing Special Purpose Transmission License in the Kingdom of Cambodia	Ministry of Industry, Mines and Energy	July 21, 2006
12	Specific Requirements of Electric Power Technical Standards of the Kingdom of Cambodia	Ministry of Industry, Mines and Energy	July 17, 2007
13	Regulations on General Principles for Regulating Electricity Tariffs in the Kingdom of Cambodia	Electricity Authority of Cambodia	October 26, 2007
14	Procedures for Data Monitoring, Application, Review and Determination of Electricity Tariff	Electricity Authority of Cambodia	October 26, 2007
15	Grid Code	Electricity Authority of Cambodia	May 22, 2009
16	Decision on limiting the electricity connections fees and deposits for electricity connection requests in the Kingdom of Cambodia.	Electricity Authority of Cambodia	October 26, 2007
17	Decision on limiting deposit, connection fee Consumption, and Fee for Electricity Providers execute in Electricity Supply in the Kingdom of Cambodia	Electricity Authority of Cambodia	November 15, 2015
18	Decision on revising connection fee and deposit from EDC's supply system	Electricity Authority of Cambodia	November 25, 2015
19	Decision on Amendments to the Decision on limiting connection fee and deposit electricity consumption and serving fee for electricity providers to provide in electricity supply in the Kingdom of Cambodia	Electricity Authority of Cambodia	December 28, 2015
20	Regulations on General Conditions for connecting Solar PV Generation sources to the Electricity Supply System of National Grid or to the Electrical System of a Consumer connected to the Electricity Supply System of National Grid	Electricity Authority of Cambodia	January 26, 2018

Source: "Report on Power Sector of the Kingdom of Cambodia from Data for the Year 2019", EAC 2020.

Cambodia's current grid code, issued by EAC in May 2009, remains the most recent technical manual providing guidelines around power system operations. Through JICA's technical assistance, the "Specific Requirements of Electric Power Technical Standards (SREPTS) on Thermal Generation, Transmission, Substation and Distribution" was prepared between 2004 and 2007 and promulgated as regulation in July 2007; likewise, SREPTS on Hydropower was also prepared between 2008 and 2009 and promulgated as regulation in 2010. EAC issued further regulations for connecting solar PV plants to the grid in January 2018, which includes process and technical rules regarding interconnection as well as certain operational restrictions.

The 2009 grid code document includes provisions for ancillary services; in practice however, EDC implicitly relies on the Vietnam grid, to which it is synchronously interconnected, to provide frequency response.

3.4.3 TRANSMISSION INTERCONNECTION

Currently, Cambodia imports electricity from all neighboring countries, including Lao PDR, Thailand, and Vietnam. Since 2015, Cambodia has had a fully integrated high-voltage transmission system in place. 230 kV and 115 kV lines connect the Phnom Penh area with power plants and imports. EDC extends medium-voltage supply to other licensees through three separate medium voltage distribution systems. REEs supply customers in rural areas through distribution mini-grids, many of which are now also connected to the national grid.

The national grid is interconnected to Vietnam synchronously via a 230 kV line in the southeast; the Cambodian portion of the grid synchronized with Vietnam is operated in large part by Vietnam. [5]Cambodia also relies on power supplies from Thailand in the northwest and from the Lao PDR in the northeast via separate 115 kV links [9]. In addition, Cambodia imports power at 22 kV from the Lao PDR, Thailand, and Vietnam to supply areas along the border.

Since 2014, there have been several transmission improvement projects completed, adding or upgrading transmissions lines and upgrading substations. These projects were funded under EDC budget or with support from JICA and the Export–Import Bank of China. The 2015 PDP includes development of over 300 km of 500 kV transmission lines linking Phnom Penh with neighboring provinces as well as additional projects such as a 500 kV line from Lao PDR and a double-circuit river crossing at 500 kV to evacuate power from the Lower Sesan II hydropower plant.

3.4.4 VRE INTEGRATION

At the end of 2017, the EAC reported that the total domestic installed capacity was 1,878 MW, of which 980 MW (52%) was hydropower, 564 MW (30%) was coal-fired, 295 MW (16%) was diesel, 29 MW (less than 2%) was biomass, and 10 MW (less than 1%) was solar [8]. Cambodia enjoys some of

[5] "The Study on Power Network System Master Plan in Lao People's Democratic Republic", JICA. 2020. Section 19.1.2; "Cambodia Energy Sector Assessment, Strategy, and Road Map", ADB. 2018, page 18; and, "Lao PDR Energy Sector Assessment, Strategy, and Road Map", ADB. 2010, footnote 64.

the highest solar resources in the GMS having a potential of over 8000 MW. By the end of 2017, Cambodia had installed over 60,000 solar home system's (SHSs) as part of the SHS program of the REF. Cambodia's technical wind potential is estimated to be from 18 MW to 72 MW.

In 2017, at the government's request, ADB developed a preliminary national solar photovoltaic (PV) grid integration study and road map for EDC. Results show that with currently available technologies, 150 MW of solar could be added to the grid by 2020 (100 MW in Phnom Penh and 50 MW throughout the rest of Cambodia) and up to 350 MW by 2030, with no major impact on the grid and no additional technical upgrades required for the existing transmission system. ADB completed a country-wide solar generation master plan for EDC that includes impacts and recommended actions to prepare the grid for solar penetration scenarios of greater than 1,000 MW by 2030 [9]. Both the grid integration study and solar generation master plan were prepared for EDC on a confidential basis. In 2019, the ADB supported an EDC auction for 60 MW of solar PV capacity that yielded a starting tariff of 3.9 US cents/kWh. Bids for a follow-on auction for an additional 40 MW were accepted in March 2021, and the auction was still adjudicated with ADB support as of the date of the present report.

3.4.5 TECHNICAL GAP ANALYSIS

Cambodia's grid code and other associated legal documents fall short of regional and international best practices on the following topics:

i. The connection requirements for HVDC interconnects are not specified in the grid code because Cambodia does not have any at present. However, further regional grid integration projects may include cross-border HVDC connections.
ii. The grid code itself does not provide any guidelines with regards to asynchronously connected generators, though as noted above, EAC issued regulations in 2018 for connecting solar PV plants to the grid, which includes process and technical rules regarding interconnection as well as certain operational restrictions.
iii. The grid code does not specify operational planning and scheduling requirements regarding generator availability.
iv. The grid code does not specify load frequency control and reserves requirements; market policies or codes; capacity allocation and congestion management; electricity balancing.

3.5 VIETNAM

3.5.1 POWER SYSTEM OVERVIEW

The management of the energy sector in Vietnam is mainly the responsibility of the Ministry of Industry and Trade (MOIT), both as line ministry and as ministry with oversight responsibility of state-owned energy enterprises. The Electricity Regulatory Authority of Vietnam (ERAV) was set up in 2005 under the MOIT. The Institute of Energy is an energy research and planning institute set up under the MOIT 20 years ago [12]. It conducts research on national energy strategies, policies, and development plans.

Vietnam Electricity Group (EVN) is the largest power company in Vietnam. EVN was formed in 1995 as a vertically integrated, state-owned corporation responsible for Viet Nam's power subsector. EVN is still the main actor in the power subsector with wholly owned subsidiaries, three power generation corporations (GENCOs), one power transmission corporation (National Power Transmission Corporation - EVNNPT), and five regional power distribution corporations (for the North, Central, South and the two cities of Hanoi and Ho Chi Minh), while managing the operation of the national power system through the National Load Dispatch Centre.

In 2017, installed power-generation capacity in Vietnam amounted to 42 GW, of which 38% was hydropower and 34% was coal-fired thermal power. Vietnam has large reserves of primary energy resources, such as coal, oil, natural gas, and water for hydropower generation. It also has a high potential for renewable energy resources such as biomass, solar, and wind. Hydropower still dominates and accounts for a significant proportion of the power generation mix. However, its share is expected to fall to under 20% by 2030. Instead, the share of coal-fired power plants is expected to grow rapidly to about 50% in 2030.

3.5.2 APPLICABLE GRID CODE DOCUMENTS

Vietnam's power sector has developed rapidly since the 1990s to become a top performer among developing countries. This success has occurred mostly under a state-owned utility, Electricity Vietnam. Vietnam's 2004 Electricity Law has provided the framework to develop a competitive power market, unbundle Electricity Vietnam, set prices that better reflect costs, promote private investment, and establish a regulatory authority [13]. In 2005, the Electricity Regulatory Authority of Vietnam (ERAV) was established, with responsibilities including to: set grid codes and standards; issue licenses and monitor compliance; review power sector plans and financing needs; advise on tariffs; and prepare and enforce regulations for competitive power markets. In order to make the electricity market more competitive, in 2010, MOIT set the terms for standard power purchase agreements (PPAs), issued a new grid code, and moved the Institute of Energy from EVN to the Ministry.

In 2015 MOIT implemented Government Decree No. 25/2016/TT-BCT which comprised a number of circulars entitled "Regulations on the Electricity Transmission System" and which serves the purposes and functions of a grid code. Implementation is under the authority of ERAV. The ERAV is also tasked with detailing technical requirements associated with the incorporation of VRE generation. Electricity Vietnam is tasked with implementing the code and executing the roles of System Operator and Electricity Market Operator. The code came into effect in January 2017.

The code regulates the activities of the following entities concerning the transmission grid:

- transmission network operator;
- electricity system and market operator;
- electricity wholesalers;
- electricity distribution units;
- electricity retailers;
- generating units over 30 MW capacity;
- electricity customers receiving electricity from the transmission grid;
- EVN; and
- other organizations or individuals.

3.5.3 TRANSMISSION INTERCONNECTION

The power transmission system operates at 500 kV and 220 kV levels and is the responsibility of NPT. As of 2014, transmission assets comprised more than 21,900 MVA of capacity at 500 kV substations and more than 30,726 MVA of capacity at 220 kV substations, and over 6,755 km of 500 kV lines and 12,513 km of 220 kV transmission lines. The NPT also operates and maintains 43 km of 110 kV lines and 110 kV substations with a total capacity of 3,175 MVA. The transmission system performance has improved over the past decade, and transmission losses have reduced from 8.2% in 2004 to 2.5% in 2014.

Currently, Vietnam has some cross-border power transmission connections with China, Lao PDR, and Cambodia. Vietnam started importing electricity from the PRC in 2004, increasing the imports from 383 GWh in 2005 to 2,025 GWh in 2014 through two 220 kV lines and three 110 kV lines. The imports from Lao PDR started in 2013, with 450 GWh imported through two 220 kV transmission lines from Xekaman 3 hydropower project. Vietnam has been exporting power to Cambodia through synchronous 220 kV transmission lines since 2009, reaching 885 GWh in 2014 (nearly 25% of the power consumption in Cambodia).

3.5.4 VRE INTEGRATION

Vietnam has substantial potential for renewable energy, especially solar photovoltaic, wind, biomass and small hydropower. However, current renewable energy generation is negligible apart from small hydropower. A wind atlas prepared in 2011 for Vietnam recorded the total wind energy potential at about 27,750 MW. However, there are only three grid-connected wind power plants in operation with a total capacity of 52 MW. The total technical potential for solar power generation in Viet Nam is estimated at around 13,000 MW. Recently, the government has also supported rapid growth in renewable energy through feed-in tariffs solar, floating solar, onshore wind, and offshore wind. In 2019 alone, Vietnam added over 4 GW of solar PV, and there are over 20 GW of approved wind and solar projects in the pipeline.

Some key obstacles to more active utilization of renewable energies are the lack of:

i. PPA bankability;
ii. strong institutional and regulatory frameworks to support renewable energies and effectively facilitate the development of a renewable energy market and industry;
iii. a strong supporting mechanism and fund for upfront investment; and
iv. technical capacity.

The government is presently considering a draft strategy for renewable energy development in Vietnam up to 2020, with outlook up to 2030. A renewable energy master plan and a renewable energy law also are being prepared. The revised PDP VII envisages increasing the share of renewable in the energy mix to 6.6% in 2020 and 10.2% in 2030. In particular, the total wind power capacity will be increased from the current level, which is negligible, to around 1,000 MW by 2020 and 6,200 MW by 2030. The revised PDP VII calls for the introduction of modern technologies to improve the quality of electricity supply, minimize power loss, ensure renewable energy integration, and promote demand-side management. Based on this direction, the smart grid road map was approved in November 2012 stipulating completion of high-voltage supervisory control and data acquisition, introduction of advanced metering infrastructure and other smart grid technologies at the distribution level, integration of distributed renewable energy, and development of the necessary regulatory frameworks.

3.5.5 TECHNICAL GAP ANALYSIS

The grid code has robust metrics for supply reliability targets (in terms of voltage levels, frequency, stability, allowable variations under normal and emergency conditions, power quality, permissible harmonics, voltage flicker, maximum short circuit levels) and indication of commitment to maintain customers' quality of supply and customer service. All provisions are comparable with accepted standards and would provide no foreseeable impediment to regional integration.

The requirements and procedures for grid development covering (i) investment planning and approvals and (ii) identification of system constraints appear to be insufficient. The planning horizon of 2-4 years is too short in the context of grid development. Furthermore, the criteria for grid investment are not specified. There is no explicit requirement for systematic contingency (N-1/N-2) analysis that would demonstrate adequate security level for transmission system operation. These deficiencies could represent a barrier to strategic development towards broader market integration if developed appropriately.

The operating modes which regulate the actions of the system operator are classified as follows:

- Normal operation mode
- Operating in a warning mode due to:
    - Insufficient regulating reserve
    - Transmission line loading near limits
    - System overvoltage/ undervoltage condition
    - Natural disaster or national defense emergency
- Emergency mode
    - Operating outside one or more permissible ratings
- Extreme emergency
    - Overloading to failure of a component
    - Management of emergency failure
- Restoration mode

The need for emergency and extreme emergency modes is indicative of insufficient depth of contingency analysis during system planning/ system development. More highly developed jurisdictions only have normal and abnormal modes with the duty of the system operator being to return the system from abnormal to normal state in the shortest possible time. The existence of emergency and extreme emergency states could be a disincentive for regional transmission systems to interconnect with the Vietnam system.

Another gap in the grid code is lack of emphasis on testing the system adequacy "by valid simulation under all credible N-1 (and in places) N-2 contingency events," which is the gold standard in planning of large transmission systems, which would be the requirement for integrated transmission systems across ASEAN. Nevertheless, the procedures, duties and responsibilities set out in the grid code are up to date and the most advanced in the region, which should serve the interests of regional interconnection without much modification of technical provisions.

3.6 THE PHILIPPINES

3.6.1 POWER SYSTEM OVERVIEW

The Philippine economy is the third largest in Southeast Asia, ranking only behind Indonesia and Thailand. The power system in the Philippines consists of three grids: Luzon, Visayas, and Mindanao, all operating at 60 Hz. The body for governing and developing policy within the country's power sector is the Department of Energy (DOE). The DOE is responsible for energy policy and planning including the formulation of the PEP 2017–2040 and the Power Development Plan. Other government bodies include the Philippine Competition Commission established under the Philippine Competition Act of 2015. The Philippine Competition Commission is mandated to promote free and fair competition across all sectors. The Electric Power Industry Reform Act (EPIRA) passed in 2001 is the main foundation of regulation in the energy sector. By the end of 2013, the power sector in the Philippines had become one of the most extensively privatized power sectors in the region [19]. The National Electrification Administration (NEA) is a government-owned and controlled corporation responsible for promoting full electrification in the Philippines with a focus on the numerous electric cooperatives that tend to serve less developed areas.

In 2016, the total installed in the Philippines' generating capacity had reached over 21 GW. Natural gas and coal remain the predominant indigenous fossil fuel resources in the Philippines. Philippines also has significant geothermal capacity. The estimated renewable energy resource potential is 13 GW for hydropower and 76 GW for wind based on 2014 National Renewable Energy Laboratory geographic information system data [18].

3.6.2 APPLICABLE GRID CODE DOCUMENTS

The Electric Power Industry Reform Act of 2001 mandated the creation of the Energy Regulatory Commission (ERC). The Act mandates the ERC to promote and enforce a National Grid Code and a Distribution Code which shall include, but not limited to: (a) Performance Standards for TRANSCO O & M Concessionaire, Distribution Utilities and suppliers, and (b) Financial Capability Standards for the Generating Companies, the TRANSCO's Concessionaire, Distribution Utilities and Suppliers. The Act also mandates the ERC to enforce compliance to the Philippine Grid Code, the Philippine Distribution Code and the Market Rules and to impose fines and penalties for violations of their provisions. The Philippine Grid Code was prepared using a functional rather than an organizational format so that it will remain robust and require minimum changes as the Philippine electric power industry is transformed to its new organizational structure. The Philippine Grid Code is intended to be used along with the Market Rules of the Wholesale Electricity Spot Market to ensure the safe, reliable and efficient operation of the Grid. The Philippine Grid Code 2016 Edition was drafted by Grid Management Committee then reviewed and approved by ERC. Furthermore, in 2018, ERC approved Resolution No. 02, Series of 2018, "A Resolution Approving the Philippine Distribution Code (PDC) 2017 Edition", which updated The Philippine Distribution Code 2016 Edition.

3.6.3 TRANSMISSION INTERCONNECTION

The Philippines has a population of more than 100 million, the 12th-largest nation in the world, spread over 7,000 islands, presenting several challenges for electricity infrastructure. Luzon (which includes Manila), Visayas and Mindanao are the three main Philippine islands; Luzon and Visayas are currently interconnected. The transmission grid in these three major islands is operated by the National Grid Corporation of the Philippines (NGCP). The island of Luzon accounts for 75% of Philippine's energy demand and 73% of installed capacity, with Visayas and Mindanao accounting for 13% and 12% of power demand, respectively. The major transmission grid infrastructures are in Luzon and Visayas, which are interconnected via a submarine HVDC link since 1997 [19]. The Visayas grid is in turn composed of five sub-grids in different islands, interconnected via submarine AC lines.

Grid infrastructure across the Philippines faces increasing pressure for expansion and reinforcement to support demand growth. Grid development is invariably complicated by the difficulties of securing rights of way. The addition of significant renewable energy capacity (mainly solar) has created grid congestion that limits the potential benefit of renewable energy resources in some locations. In Luzon, the NGCP's focus is on strengthening the transmission system and improving reliability and resilience. In Visayas, the NGCP is procuring additional ancillary services, particularly regulating reserves (frequency response), to manage the effects of fluctuations in supply due to solar generation variability. In Mindanao, which has experienced sustained supply deficits in the past, the focus has largely been on transmission projects that facilitate the entry and full utilization of new generation capacity, particularly new coal-fired plants. Increased interconnectivity between the major grids is also a major long-term priority of the NGCP.

3.6.4 VRE INTEGRATION

In 2017, renewable generation capacity mainly from solar and wind reached 1.2 GW, or 6% of total dependable generation capacity in the Philippines. Investments in renewable energy generation are incentivized by FiT and other measures adopted by the Philippines through the 2008 Renewable Energy Act. As a result, there has been rapid penetration of other renewable sources over the past few years, with wind, solar and biomass totaling 1,243 MW in 2017, up from 93 MW in 2013. Most of renewable energy generation continues to be produced by hydro and geothermal power plants, amounting to 11% and 10% of generation in 2017.

As of 2019, VRE resources account for 7% of the total installed capacity in the Philippines. Under the NREP of 2011, the policy framework for implementing the Renewable Energy Act, the DOE is aiming to almost triple the renewable energy capacity from 5,438 MW in 2010 to about 15,304 MW by 2030. This highly ambitious plan comprises technology-specific targets by region which notably includes an additional 1,495 MW (75%) of geothermal capacity by 2030, 5,394 MW (160%) of hydropower, and 2,345 MW of wind power. Solar generation is expected to increase from the current 1.2% of 23 GW to at least 3.5% of 43 GW installed capacity by 2040.

There are some regional interconnection and transmission infrastructure restrictions limiting VRE integration. Backbone transmission projects are planned to address line congestion problems in the Visayas, and the Philippines is undergoing a process to establish competitive renewable energy zones and smart grid technology development. The DOE has recognized that energy storage could stabilize the Visayas grid which has experienced load dropping due to the addition of VRE. However, various stakeholders have raised concerns that there is a lack of governing policy framework for energy storage regulation and operation.

3.6.5 TECHNICAL GAP ANALYSIS

The Philippines updated its grid code for VRE interconnection and adopted a comprehensive VRE forecasting framework. The grid code and wholesale electricity market rules provide a strong enabling framework. However, the dispatch rules in the wholesale electricity market lack economic curtailment, provide preferential dispatch to VRE, and implement curtailment for reliability reasons only. As the penetration of VRE increases, these rules may require revisiting to maintain grid stability as well as efficient market outcomes.

3.7 INDONESIA

3.7.1 POWER SYSTEM OVERVIEW

The Indonesian power system [1] is under state owned utility company Perusahaan Listrik Negara (PLN). Privately participation in generation is allowed through competitive tenders. Indonesia is split up into several synchronous systems due to its topology as an archipelago state. The total generation capacity comprised of 41 GW owned by PLN, 14 GW owned by IPPs, and a considerable amount of captive generation capacity that is usually not connected to the public grid. There is no established power market in Indonesia, but PLN controls the dispatch schedules and prices are regulated by government through subsidies.

3.7.2 APPLICABLE GRID CODE DOCUMENTS

In Indonesia, the Grid Code is stipulated through the Regulation of the Minister of Energy and Mineral Resources under the Ministry of Energy and Mineral Resources (MEMR). Currently, there are four Grid Code documents officially published in Indonesia.

- Grid Code for the Java-Madura-Bali Electric Power System Network (EPSN), which is regulated through MEMR Regulation Number 03 of 2007 (GDE 2007).
- Grid Code for the Sumatra EPSN, which is regulated through MEMR Regulation Number 37 of 2008 (GDE 2008).
- Grid Code for the Sulawesi EPSN, which is regulated through MEMR Regulation Number 02 of 2015 (GDE 2015).
- Grid Code for the Kalimantan EPSN, which is regulated through MEMR Regulation Number 18 of 2016 (GDE 2016).
- There is an additional connection code published on 2014 for Renewable Energy Generation Plants (REGP) which includes guidelines for Connecting Renewable Energy Generation Plants to PLN’s Distribution System (up to 20 KV) having installed capacity less than 10 MW.

3.7.3 TRANSMISSION INTERCONNECTION

Presently, integrated electrical grid systems exist separately in Java–Bali–Madura and Sumatra. The Java–Bali–Madura system is interconnected with 500 kV and 150 kV lines, while Sumatra is interconnected with 275 kV and 150 kV lines [2]. PT PLN plans to expand the interconnection project through an HVDC electricity transmission system. Combining the two integrated systems is expected to facilitate cheap and efficient energy use. The interconnection system will be designed to distribute 3000 MW from Sumatra to Java–Bali. It will consist of an AC to DC power converter station in Muara Enim, South Sumatra. DC power will then be converted to AC (inverter station) in Bogor, West Java. If a Bangka NPP becomes possible, this power transmission integration will ease the electricity distribution from Sumatra to Java. Currently, on Kalimantan Island, a 150 kV line interconnects the provinces of Central Kalimantan, South Kalimantan and East Kalimantan.

3.7.4 VRE INTEGRATION

The nation's first operational wind turbine park, the Sidrap Wind Park (75 MW), is in South Sulawesi. The Tolo 1 Wind Park (72MW) is expected to start operations any time soon in the same region [3]. Together, these parks amount to just over 5% of the total installed power capacity in South Sulawesi. The government targets for renewable energy are 23% in 2025 and at least 31% in 2050. However, the government is expected to rely more on geothermal and hydropower to achieve its targets. VRE capacity is not expected to rise above 2.5% of the total installed capacity in Indonesia until 2030 [4].

3.7.5 TECHNICAL GAP ANALYSIS

The ACE study ("Report on ASEAN Grid Code Comparison Review") identified several technical gaps with the Indonesian grid code.

- The documents are very brief regarding technical requirements and should be more specific for clarity.
- The transmission codes require no specific fault behavior from generators. Generators may currently trip outside of the given frequency range, and no provisions are given for under or over voltage events. This is particularly true for VRE plants connected to the transmission grid. Additional requirements for Fault Ride through (FRT) and time limited operation outside of the normal frequency range should be added.
- SCADA connection is required under the transmission codes, but no information on the used protocols is given in the connection code.
- The REGP code sets requirements for off-unity power factor operation of generators, but requires them to, under normal conditions, control power factor and not voltage.
- The transmission codes contain no specifications on compliance mechanisms. It is clear from the codes that the generator is required to comply with the requirements presented, but there are no specific descriptions of the application and connection process, the required documentation, or the compliance tests that need to be conducted.
- It is clear that PLN is authorized to conduct compliance tests, but a lack of clarity concerning these may present a barrier to investments in renewable energy.
- A well-defined connection process must be defined for system reliability and stability.
- A large part of PLN Interconnection Guideline for RE is dedicated to the connection of small renewable to distribution lines compared to the connection process to transmission lines [1].

These findings are not surprising since Indonesia's grid code documents are increasingly dated and do not reflect recent development regarding VRE technology and corresponding best practices to manage VRE integration.

3.8 MALAYSIA

3.8.1 POWER SYSTEM OVERVIEW

The Malaysian power system is split up into two synchronous zones – (i) the Malay Peninsula, run by Tenaga Nasional Berhad (TNB); and (ii) the grids of Sarawak, Sabah, and Labuan, run by Sarawak Energy Berhad (SEB) and Sabah Electricity Sdn. Bhd. (SESB). TNB controls generation, transmission, and distribution for 80% of the total demand in its system. IPP operations are permitted with the respective utility acting as the single buyer; all utilities also currently own over 50% of the total generation capacity. As of 2017, the Malaysian Energy Commission has undertaken the first step towards a free wholesale power market by introducing the New Enhanced Dispatch Arrangement (NEDA). This requires the utilities to determine the least cost dispatch with a marginal payment for utility-owned generators, IPPs, IPPs with expired PPAs, and industrial users.

3.8.2 APPLICABLE GRID CODE DOCUMENTS

The Malaysian Grid Code and the Malaysian Distribution Code published by TNB in 2013 and 2012 are applicable to TNB grids on the peninsula, while there are separate Sabah and Labuan Grid Code document published by SESB. No information was provided for the state of Sarawak. The Renewable Energy Rules 2011, published by the Malaysian government and amended in 2014, outlines the legal rules for connecting renewable energy sources to the grids. The technical requirements are not mentioned in the Renewable Energy Rules 2011 but describe connection processes and time schedules; it limited renewable generation units to a size of 30 MW.

The Guidelines on Large Scale Solar Power Plants for Connection to the Transmission and Distribution Electricity Networks, published by the Regulatory Commission in 2016 and revised in 2017, allows solar PV generators between 30 - 50 MW to connect to the grid, provided they fulfil the requirements as per code. Malaysia also has the TNB PV Guidebook which was developed by TNB and University Tenaga Nasional (UNITEN).

3.8.3 TRANSMISSION INTERCONNECTION

A 500 kV line covering 522 km forms the backbone of the transmission system in Peninsular Malaysia. The National Grid is interconnected in the north to EGAT's transmission system via a 300 kV HVDC interconnection with 300 MW capacity as well as a 132 kV HVAC double circuit overhead line of 90 MW capacity. In the south, the National Grid is connected to the transmission system of Singapore Power Limited (SP) at Senoko via two 230 kV submarine cables with a transmission capacity of 200 MW each.

3.8.4 VRE INTEGRATION

Malaysia gets only 2% of its energy from renewable sources, mostly from solar PV, despite targets of achieving 20% penetration by 2025 [7]. About 50% of the target is expected to be met with solar. Malaysia has among the highest potential for solar uptake as it is strategically located near the equator. The estimated potential for solar is up to 6,500 MW. The FiT program was introduced in 2011. The Energy Commission (EC) of Malaysia started the competitive bidding process for Large Scale Solar (LSS) in 2016, offering a total of 434 MW for Peninsular Malaysia; subsequent rounds of LSS bidding offered 563 MW in the second round and an estimated 500 MW for the third round in 2019 [5].

Malaysia has strict rules for VRE integration into the national grid. Only renewable generators having frequency and voltage control are allowed to connect, according to the grid code. The renewable energy rules 2011 states the rules for connecting renewable generation to the distribution grid. Generators with an installed capacity larger than 72 kW must apply to the operator for a connection point before they can apply for the FiT. For generators larger than 180 kW, this application process may involve a Power System Study and a requirement to pay the cost of all connection related procedures, which may create barriers for renewable energy development.

TNB has also issued a PV Guidebook which sets more detailed requirements for distributed generation.

3.8.5 TECHNICAL GAP ANALYSIS

The current documents governing grid code in Malaysia address most requirements for grid operations, at least partially. There are however some potential areas for improvement.

At present, there are no guidelines in TNB regulations, the Malaysian Distribution Code, or Malaysian Standards on the maximum percentage of voltage fluctuation allowed due to intermittent generation like solar PV, although the Malaysian Distribution Code allows voltage fluctuation of ± 3 % for load switching. The current code does not mention direct rules on the ability of units to receive active (and reactive) power set points per remote control [1]. The PV guidebook requires solar PV generators to disconnect at 49.5 Hz and 50.5 Hz; however, this is not a recommended practice and may affect the system stability and result in a complete blackout.

Likewise, voltage control from generators smaller than 5 MW is neither required nor allowed. Even if the functionality is currently not used, the capability to control the voltage at the connection point with reactive power should be required for the future, especially if there is a proliferation of smaller solar PV projects under the 5 MW threshold. Similarly, solar PV penetration limits for feeders should be determined on a regular basis instead of setting fixed limits, with additional studies mandated by the grid code or guidelines if a certain threshold is crossed.

The Guidelines on Large Scale Solar Power Plants for Connection to the Transmission and Distribution Electricity Networks contain even more detailed process descriptions, including draft PPAs, guidelines on the tendering of PV capacities, connection point specifications, asset demarcation specifications and the entire application and connection process. The document is very well thought out and even exceeds international standards of good practice and should be used as a template for other types of generators as well, including for larger wind plants that may be planned in the future.

The ACE study ("Report on ASEAN Grid Code Comparison Review") found the lack of detailed requirements in Sabah/Labuan grid code to be a primary gap in the Malaysian grid code that should be addressed. It may be sensible to adopt an adapted Malaysian Grid Code for Sabah/Labuan and Sarawak as they are structurally similar.

4. REVIEW OF REGIONAL GMS GRID CODE

4.1 PROPOSED GMS REGIONAL GRID CODE (RGC)

The GMS Regional Grid Code (RGC) is a key regulatory instrument required to support the pursuit of the GMS energy sector's policy objectives. The GMS RGC defines the technical requirements and establishes the rules and procedures for GMS Regional Grid Code Parties, namely the six GMS member countries, to use the power system and to permit the power system to be planned and operated in manner that is safe, reliable, efficient, and economical. The GMS RGC was prepared under two ADB regional technical assistance (RETA), RETA-6440: Facilitating Regional Power Trading and Environmentally Sustainable Development of Electricity Infrastructure in the GMS and RETA 8830: Harmonizing the GMS Power Systems to Facilitate Regional Power Trade. It is in the process of formal enforcement by the GMS countries.

The objectives of the GMS Grid Code implementation are: (i) harmonization of the National Grid Codes and the Operational Practices for the synchronous operation of GMS areas; and (ii) the development of the regional power exchanges through synchronized operations.

The proposed GMS RGC consists of following sections:

1. Preamble
2. Governance Code
3. Connection Code
4. Operational Security Code
5. Operational Planning and Scheduling Code
6. Load Frequency Control and Reserves Code
7. Emergency and Restoration Code
8. Market Code
9. Metering Code
10. Operational Training Code
11. Glossary of Terms
12. GMS Strategic Planning Document

4.2 TECHNICAL AND MARKET ISSUES ADDRESSED IN THE GMS REGIONAL GRID CODE

The key technical and market framework required to form a harmonized GMS grid forms the basis for the GMS RGC, and covers the following aspects:

- General Technical Considerations – RGC overarches National Grid Codes that can be more stringent to suit local regulatory requirements.
- Harmonization of National Grid Codes – compatibility of differences among measurements, methods, procedures, schedules, specifications, or systems.

- Frequency Regulation – Primary, Secondary & Tertiary Reserves for containment of frequency fluctuations to maintain synchronous power balancing.
- Reliability Standards – Planning Codes to ensure problem in one region not being transferred through interconnections to another.
- Variable Renewable Energy – Mitigate impacts of VRE intermittency, enable load shifting and optimize use of GMS hydro storage capability.
- System Flexibility – Ability to modify regional transmission and distribution grid codes to enable new distributed technologies to compete in power market.
- TSO Operations – coordination between independent national TSO/DSOs for load balancing and during emergencies.
- Communications, Control & Data Management– SCADA for load dispatch and Emergency operations, cybersecurity & confidentiality of data.
- Regulation & Pricing – Barriers, Open Access, Wheeling Charges, Short Term Trading Rules, Balancing Mechanism – covered under ADBKP Feb 2020.

4.3 GAP ANALYSIS OF GMS RGC

The GMS Regional Grid Code has been formulated based upon the European (ENTSO-E) model. The European transmission network planning and operation is quite different compared to the GMS and ASEAN transmission networks. The European electricity market has matured over the years with strong grid infrastructure, uptake of technologies such as FACTS, HVDC, inverter-based grid supporting generators, and well-formed national grid codes.

As the proposed regional grid code was based on ENTSO-E, there are multiple disagreements between the RPTCC and the national transmission system operators. For each section of the proposed RGC, national transmission system operators of the GMS countries have flagged discrepancies with their national grid codes and standards which could jeopardize the formulation of a harmonized GMS grid.

There are some key differences in the GMS RGC and national grid codes of the GMS countries:

- The metering accuracy for the grid frequency shall be at least ± 10 mHz to ± 20 mHz as per Thailand's TSO; GMS RGC recommends only 10 mHz.
- Over-frequency ride through criteria should be set to 51Hz as per Thailand's TSO, whereas GMS RGC recommends above 51Hz and also envisages HVDC connections with special protection schemes.
- The Chinese TSO stipulates a reactive power compensation requirement for wind farms. Reactive power compensation devices should be installed in wind farm when reactive capacity of wind generators does not match the demand of system voltage control, among which at least 50% of the capacity should be dynamic reactive compensation device. But GMS RGC disagrees and sticks to the EU grid code which is set at 0.95 total range, 0.5 lagging and 0.45 leading.
- Chinese TSO requires flexible maximum fault clearing time for 500 kV and higher short circuit current levels which GMS RGC disagrees with.
- Vietnam's grid code stipulates frequency bands with minimum ride through time for hydro and thermal power plants which is in contrast with GMS RGC.

- The power factor requirement in Vietnam's national grid code is different compared with the GMS RGC, which has less stringent standards.
- The fault levels for the 220 kV network stipulated by Vietnam's grid code are different.
- The maximum fault clearance time stipulated by Vietnam is different.
- Dynamic performance test of excitation system is not addressed in the GMS RGC but is defined in some of the national grid codes. This varies.
- The droop settings of the GMS RGC are too wide compared with the Vietnam's grid requirements.
- Operational contingency scenarios are not defined or detailed in GMS RGC
- The time period of the emergency state is higher in GMS RGC than in Chinese grid code.
- Thailand's TSO requires each TSO within the GMS to perform contingency analysis every 15 mins in real time to determine the system state. But this is neither possible nor required in the GMS RGC.
- China's TSO raised the issue of confidentiality and non-sharing of some of the key information with the other GMS TSOs. Data sharing is one of the major bases for regional power market integration without which it cannot be fully functional.
- During extreme contingency events, China's TSO wants to avoid setting intentional time delay in addition to the operating time of the relays and circuit breakers. This was not agreed to by RPTCC for the GMS RGC.
- There is disagreement on the allocation of frequency leaders.
- Thailand's TSO disagrees with GMS RGC methodology to determine the cause of imbalance energy based on NERC (North American standard) as the GMS RGC was based on ENTSO-E standards.

For the most part, these differences arise where the national grid code standards are already more stringent that equivalent standards in the GMS RGC, particularly for Thailand, Vietnam, and China. This is not surprising since they are the three most advanced grids in the GMS and the proposed regional grid code was likely accommodating countries with less mature grid code documents. These differences are potentially significant drawbacks of the GMS RGC, since a harmonized regional power market is less likely if the biggest grids are not aligned.

The GMS RGC is poorly formulated with regards to the technical requirements for VRE. For most of the technical requirements, GMS RGC recommends that individual TSOs stipulate the operating thresholds including ride through criteria. This approach could lead to conflict and grid instability, especially with AC-based cross-border transmission interconnections that already exist (there is already grid synchronization between Lao PDR and Thailand and between Vietnam and Cambodia). Such requirements must be addressed in consultation with the national TSOs.

Although these differences can be addressed through negotiation and consultation to formulate an effective GMS RGC that can facilitate a harmonized GMS grid, the greater challenge lies with how far some countries lag the more advanced markets. There are considerable technical gaps in planning and operations in Myanmar, Lao PDR, and Cambodia that must be bridged. For this reason, the JICA study on the Lao PDR power network system master plan concludes that a harmonized grid can only be realized after 2030.

5. COMPARISON OF GRID CODES

A grid code recommendation is only possible by comparing the existing grid codes in each member states of ASEAN. The comparison is based on certain important parameters like demand connection policies, synchronous generator requirements, HVDC connections, emergency response and restoration, operational security, operational planning and scheduling, load frequency control and reserves, speed governing system, reactive power handling, voltage levels, and frequency control standards. The information from GMS RGC and European code are also taken for further comparison of ASEAN member states' grid codes with the GMS code and European code. These comparisons can help for gap analysis and further recommendations for common ASEAN wide grid code.

5.1 COMPARISON

Comparison of ASEAN member states gride codes and GMS gride code is provided in Annex A: Comparison of Grid Codes.

Comparison of grid codes and gap analysis of Indonesia, Malaysia, and the Philippines.

The transmission system shall have a nominal frequency. In the GMS RGC, the nominal frequency is 50 Hz. Due to the dynamic nature of the power system, the frequency can change rapidly under system stress or system fault conditions. Different countries have different nominal frequencies and operation requirements. In GMS RGC, the normal operation frequency is between 49.00 to 51.00 Hz. In emergency condition frequency can go between 51 to 51.5 Hz and should be brought back to normal with in 30minutes. When the frequency is low between 47.0 to 49.0 Hz, the system recovery time can be decided by TSO, which should not be less than the time specified in the code. The normal frequency range of all countries and the emergency frequency range of all countries should be harmonized with GMS grid code for synchronous cross border interconnections.

The voltage at any point on the transmission system will normally remain within the range specified in the code, unless abnormal conditions prevail. In the GMS RGC, the normal voltage range is -10% to +11.8% of nominal value. Once the voltage deviates outside the above limits by more than -5%, the system is then operating under stress and should be brought back to normal range within 60 minutes. The higher voltage range 11.8% to 15% is to be decided by TSO. Voltage ranges of normal and emergency conditions of all countries are to be harmonized for establishing cross border transmission lines. Technical details of grid codes of Indonesia, Malaysia and Philippines with GMS grid code are given Table 5 below.

Table 5. Technical Details of Indonesia, Malaysia and Philippines

Country	Technical Gap Analysis			
	Voltage		Frequency	
	Normal(unlimited)	Emergency	Normal(unlimited)	Emergency
GMS Grid Code	-10% to +11.8%	(a) - 15% to -11% - 60 minutes (b) +11.8% to +15% to be specified by TSO	49.0 Hz to 51.0 Hz	(a) 51 Hz to 51.5 Hz – 30 minutes (b) 47 Hz to 49 HZ To be specified by TSO
Indonesia	(a) For nominal voltage 500KV and 275 KV, ± 5% (b) For nominal voltage 150 KV and 66KV, +5% and – 10%	Maximum Voltage limit (a) For 500 KV to 550KV (b) For 275 KV to 300KV (c) For 150KV to 170KV	49 HZ to 51 HZ	(a) 51.5Hz to 52Hz-15minutes (b) 51Hz to 51.5Hz-90minutes (c) 47.5Hz to 49Hz-90minutes (d) 47Hz to 47.5Hz - 6seconds
Malaysia	(a) Below 132KV, ±6% (b) 275KV and 132 KV, ± 10% (c) 500 KV, ±5%		49.5Hz to 50.5 Hz	47Hz to 52 Hz
Philippines	Nominal Voltage 500KV, 230KV,138KV,115KV and 69 KV, 95 to 105%	90 % to 110%	Nominal 60Hz 59.7 Hz to 60.3 Hz	N-1 contingency 59.4 Hz to 60.6 Hz

It is clear from Table 5 that the Philippines can only have HVDC interconnection with other ASEAN member nations because it has a nominal frequency of 60 Hz; all other countries have nominal frequency of 50 Hz. Malaysia and Indonesia have transmission voltage of 500 KV, and synchronous interconnection at 500KV is possible. The normal operating frequency of Malaysia is 49.5 to 50.5 Hz while GMS grid code specifies 49 to 51 Hz. Malaysia and Indonesia must first align their normal and emergency ranges of voltage and frequency for synchronous cross border interconnections.

In general, the following points are noted comparing the grid codes with the GMS RGC.

1. It is necessary to upgrade the grid code of Malaysia to include demand connection details, voltage / reactive power management for inverter-based generators, operational security details, capacity allocation and contingency details, and operator training and skill development system.
2. Indonesia, Malaysia and the Philippines should upgrade their grid codes to include HVDC transmission line connection and operation details, data exchange with interconnected countries, development of common analysis model, inter-area studies on system security analysis, and common metering policy.
3. Additional regulations are necessary to participate in load frequency control and procurement of reserve between countries, inter-area allocation rules for reserves, power import/export management, and preparation of precise data with necessary details for data exchange and implementation of a common regional market.

Comparison of grid codes and gap analysis of Cambodia, Lao PDR, Myanmar, Thailand and Vietnam

The comparison of the GMS grid code with national grid codes of Cambodia, Myanmar, Thailand, Lao PDR and Vietnam, shown in Table 6, provides the following insights.

1. The technical details regarding demand connection policies, HVDC connection details, asynchronously connected DC generators, market policy and operator training policy are either absent or should be upgraded to GMS RGC level.
2. The metering code is included in some national codes but details like ownership, position of meter, accuracy class of meter and connected CT and PT, and data requirements should be harmonized.
3. For efficient operation of regional grid and to facilitate power trade, it is important to align the national grid codes with respect to data exchange with neighboring countries; development of common analysis model; inter-area studies on system security analysis, international rules for load frequency control and procurement of reserves; inter-area allocation rules for reserves; development of power import/export management; and creation of a power market.
4. The normal frequency range of all countries except Vietnam and the emergency frequency range of all countries should be harmonized with the GMS grid code for synchronous cross-border interconnection.
5. Voltage ranges of normal and emergency conditions of all countries should be harmonized for establishing cross-border transmission lines.

Table 6. Technical Details of Cambodia, Lao PDR, Myanmar, Thailand and Vietnam

Country	Technical Gap Analysis			
	Voltage		Frequency	
	Normal(unlimited)	Emergency	Normal(unlimited)	Emergency
GMS Grid Code	-10% to +11.8%	(a) -15% to -11%, 60minutes (b) +11.8% to +15% to be specified by TSO	49.0Hz to 51.0 Hz	(a) 51Hz to 51.5 Hz – 30 minutes (b) 47 to 49 To be specified by TSO
Cambodia	Nominal Voltage 230KV,115KV. 230 KV - Range 245KV to 207KV 115 KV – Range 123KV to 103.5 KV	NIL	Nominal frequency 50 Hz 49.5Hz to 50.5 Hz	47Hz to 52 Hz
Myanmar	Nominal Voltage 500KV, 230KV,132KV, 66KV.	NIL	49.5HZ to 50.5 Hz	47Hz to 52 Hz
Thailand	Nominal Voltage 500KV, 230KV,115KV and 69 KV- Range 95 to 105%	90 to 110% of nominal value	Nominal 50Hz 49.5Hz to 50.5 Hz	48 Hz to 51 Hz
Lao PDR	Nominal Voltage 500KV, 230KV,115KV-Range 95 to 105%	90 to 110 % of nominal value	Nominal 50Hz 49.5Hz to 50.5 Hz	47Hz to 52 Hz
Vietnam	Nominal Voltage 500KV, 220KV,110KV.	NIL	Nominal 50Hz 49.0Hz to 51.0 Hz	47Hz to 52 Hz

During the 26th Regional Power Trade Coordination Committee meeting (RPTCC-26) held in Hanoi, Vietnam between November 26-27, 2019, ADB Senior Consultant Michel Caubet conducted a gap assessment of the national grid codes of Cambodia, Laos, Thailand, and Vietnam with the GMS Grid Code Technical Requirements. The presentation provides solutions to address gaps, many of which are related to the ongoing restructuring process in the power sector in these countries. The summary of results of analysis is given below:

- Third-party access: The regional grid code is the legal instrument required to establish an efficient organization and operation of the regional power trade based on the “third party access” rule. An effective and efficient operation of the regional electricity market requires adopting and implementing the third-party access rule in interconnections.
- Sector reforms: The GMS Countries are at different stages of implementation of electricity sector reforms. They are still restructuring their electricity sector.
- Institutional, Legal and Regulatory Gaps: There are gaps when comparing the requirements of the national grid codes with the requirements of the GMS grid code. Restructuring and opening third party access to cross-border trade shall progressively release the institutional and regulatory barriers identified in the initial stage of the gap assessment analysis.
- New Processes and new Practices: The adoption of the “third party access” rule induces setting up and adopting new processes and practices, which were not required in the previous “vertically integrated” organization of the sector. They are related to the introduction of the ancillary services market and the electricity balancing markets, which are both managed by the TSOs.
- Complete Restructuring: The restructuring of the electricity sector and the introduction of the new practices will progressively remove the identified gaps.
- Technical gaps: Technical gaps have been identified, caused by non- compliance with the GMS Performance Standards. They could be fulfilled by: (a) progressively increasing the generation capacities and the reserve capacities (for example: to comply with the maximum frequency deviation tolerance of 200 mHz under normal conditions and later to 50 mHz; to limit the maximum steady-state frequency deviation after contingency to 250 mHz); (b) reinforcing the transmission and distribution network capacities to comply with the other Performance Standards; (c) upgrading the control facilities with modern SCADA/EMS functions to fulfil some technical gaps like AGC, dynamic stability analysis, etc.
- Gaps caused by the expansion of the synchronous zone: Other technical gaps have also been identified, due to the expansion of the synchronous operation zone in the GMS Region. This expansion requires developing and adopting new methodologies, coordination processes, procedures and rules among the TSOs which were not necessary before. Among those new processes, we can note the following: methodology for coordinating operational security analysis, methodology for determining relevant assets for the outage coordination process, coordinated dynamic stability analysis on the synchronous area level, establishment of the common grid model and emergency & restoration plans.
- Operational Security – These requirements are new and caused by the necessity of improving drastically the operational security of the synchronous zone.

Considering these results of Caubet’s gap analysis, it is necessary for each GMS country to participate in the restructuring process and incorporate the change of practices caused by both the restructuring and the expansion of the synchronous zone. Major capacity building programs for efficient monitoring is required for the region, to complete transmission line interconnections within the targeted deadline. In addition, a Regional Electricity Regulatory Authority, Grid Code Secretariat and Grid Code

Review Panel, a Regional Power Trade Institution, and National Independent Regulatory authorities are required to enforce the GMS RGC.

6. MINIMUM REQUIREMENTS FOR AN ASEAN-WIDE GRID CODE

6.1 OVERVIEW

A grid code must satisfy certain minimum requirements to interconnect two independent power system networks and to establish power trade. These requirements are incorporated in regional grid codes. A regional grid code is necessary for sustained and significant power trade among a regional group of countries, even though they it may not replace their respective national grid codes. This structure allows flexibility for national grid codes to set country-specific requirements. The TSOs of the individual countries involved are exclusively responsible for developing the Regional Grid Code through proper analysis and consultation with the stakeholders involved. National regulators are the final authorities to approve both national and regional grid codes.

Furthermore, as VRE plays an increasingly vital role in meeting energy requirements, regional VRE grid codes are expected to become particularly important for two reasons. Firstly, some grid code requirements depend on the overall VRE penetration levels in the interconnected system. Secondly, cross-border electricity trading facilitates balancing the fluctuations caused by VRE.

Regional grid codes provide a coherent framework within which the power system can be operated more efficiently. They may allow more efficient system operation and a higher share of renewable energy and thus lower cost in the long run. The use of regional grid codes for generator requirements ensures harmonization, at least in structure if not in requirements. Such harmonization makes it easier for stakeholders to manufacture and operate assets in different countries, and for system operators to use their interconnectors more efficiently to trade more renewable energy.

However, great care must be taken when developing regional grid codes. Local and national structural peculiarities must be taken into account, especially if the grid code covers a large area with several synchronous grids. For countries with existing grid codes, drafting a good regional grid code and harmonizing all national and local documentation may mean a great deal of effort and demand major upfront investment. Conversely, regions lacking a grid code may save costs by pooling resources to write a common regional grid code.

6.2 VRE INTEGRATION

The power sector globally is pivoting towards increasing reliance on sustainable sources. The International Renewable Energy Agency (IRENA) analysis estimates that the global share of VRE can be expected to increase by as much as 20% by 2030. Countries like Denmark, Spain, Ireland, and Germany already have VRE penetration greater than 15%. To smoothly integrate these VRE sources into our existing power systems, well-defined requirements and procedures must be followed to enable co-ordination among the participants of power system and thereby maintain system stability and reliability.

The process of developing a national VRE grid code should include the following elements: preparation of technical studies, data collection and assessment of country-specific aspects; expert draft of the grid code; stakeholder consultation on the draft; grid code endorsement; implementation; and periodic revisions based on policy changes and operational experience. Many of the requirements for the connection of VRE generators depend on the specific needs and conditions of the local power system. For example, Ireland has a high share of wind power and limited interconnections, so the Irish grid code pays particular attention to frequency control requirements. The main aspects for developing a VRE grid code are size of the power system, interconnection level, voltage levels, flexibility of load and generation, characteristics of conventional generators, energy policies, VRE penetration level, and operational practices.

For reliable and safe operation of the power systems, the interconnection of VRE to the existing system must be complemented with new technologies like storage and control systems, as well as new operational practices for power systems. Together, they can increase the flexibility of an existing system and accommodate higher penetration of VRE. Successfully integration of VRE into electricity networks requires careful consideration of technology, operations, and regulation.

6.2.1 TECHNICAL REQUIREMENTS OF VRE GRID CODE

The requirements imposed on VRE generators depend on the existing and planned share of VRE in the generation pool of the system. At low VRE penetration levels, their influence on grid stability can be managed more easily. As the share of VRE in the generation mix rises, VRE generators must effectively take over a growing number of duties from the conventional generators they replace. Nearly all modern VRE generators are based on power electronic converters. These generators differ significantly in terms of behavior during network faults, emission of harmonic currents, or inherent response to frequency changes. Consequently, VRE grid codes must codify rules previously taken for granted when synchronous machines were still the prevalent generator technology. Some of the generic technical requirements necessary in a harmonized grid code to integrate VRE are detailed below.

Voltage and frequency operation ranges

Operation ranges describe how far voltages may deviate from the ideal level, which can never be attained exactly due to the physical properties of the grid, its generators, and loads. All equipment is therefore able to operate within some tolerance around the nominal values. However, larger deviations can cause permanent damage or equipment breakdown. A typical voltage tolerance band for unrestricted generator operation is ±10% of the nominal value. The frequency tolerance is usually much smaller, around ±2% in large interconnected systems.

Power Quality

Beyond magnitude and frequency, voltage and current deviations from nominal values also occur in terms of waveform distortions and short-term fluctuations. These deviations are classified according to their characteristics and can be measured with appropriate methods. They are referred to as aspects of power quality and are specific to a given location in the electricity network in a given time interval. Power quality requirements specify limits for emitting voltage disturbances and current for each asset connected to the grid. All generators including VRE at any penetration level must comply with similar limits to ensure suitable voltage quality for power system users.

Reactive Power Control

Power system operators maintain the voltages in the system within their desired ranges primarily by managing the contribution of reactive power from generators. VRE generators do not inherently provide capability to maintain the reactive power contribution. Instead, desired reactive power capability ranges must be explicitly considered when a VRE generator is being designed, and therefore may have a significant impact on generator cost.

- Wide reactive power capability and controllability of VRE generators generally allows higher VRE penetration.
- In the distribution system, wide reactive power capability can reduce grid reinforcement needs caused by VRE integration.
- In the transmission system, wide VRE power plant reactive power capability helps reduce conventional must-run capacity.

Frequency Support

VRE generators depend on the fluctuating availability of primary energy for their power injection into the system. From the perspective of the power plant dispatcher in a system with VRE priority feed-in, the aggregate of both load and VRE generation must be balanced via the conventional generation park. Tuning the capabilities of VRE generators to the requirements of power balancing during disturbances relieves the stress on conventional capacity that must be retained for frequency control.

- VRE generation is not particularly well suited to providing frequency control. However, support measures for frequency disturbances are available through VRE plant equipment.
- During episodes of over-frequency, VRE generators should first gradually reduce their power output while remaining connected to the grid. They should only disconnect at a specified threshold with sufficient margin to the nominal frequency. Such requirements are already part of most VRE grid codes.
- To provide reserve power during episodes of under-frequency, a VRE plant would need to be capable of reduced output operation mode. This involves spilling free primary energy and is still under discussion in most countries due to related issues concerning the power market and priority dispatch.

Fault Behavior

Requirements imposed on VRE generation in terms of fault behavior resemble the requirements of conventional generators. Conventional generators are inherently capable of providing high short circuit currents. However, the provision of these higher than nominal currents from VRE generators must be considered in the generator design.

- With increasing VRE power plant size and VRE penetration, VRE generators need to remain connected for a limited period during grid faults in order not to endanger the power balance.
- Due to technology constraints, VRE generators are not capable of injecting similar levels of current required for fault detection already provided by conventional generators.

Active Power Gradient Limitation

The power injection ramps caused by fluctuating primary energy become a relevant factor concerning power reserves allocated by system operators. Hence, to compensate these ramps proper measures should be taken by modifying the market structures.

- The variable power injection of the aggregated VRE generation can cause ramping requirements that increase the required reserve capacities needed to avoid power imbalance.
- Imposing ramping limits on VRE in these cases helps limit the necessary ramping reserves and thereby contributes to system efficiency.
- The effort required to implement VRE power gradient limitations depends on the cause of the power gradient.

Simulation Model

Simulations are used by system operators to analyze and predict the behavior of their system. These simulations depend on sufficiently complete and accurate power plant models for all significant types of generation. When the VRE share or plant size becomes significant, grid codes start mandating simulation models for these plants. Models have to be provided in a specified format and need to fulfil requirements on functionality and accuracy.

Active Power Management

One key task of power system operation is to balance load and generation by allocating the corresponding resources in sufficient quantity on the power markets.

- Power system operators need access to power plant dispatch for managing grid stability and congestion.
- VRE generators can access active power management if temporary power output limits are imposed. VRE generator systems thus need to integrate the facility to accept and adhere to these limits.
- VRE generators are required to provide active power management capabilities even in power markets/regulations with VRE priority dispatch.

Communication

Real-time measurement data transmission is necessary to assess the system state. Control commands such as the desired states of switching equipment or generator set points must be communicated to the corresponding actors. As VRE generation grows in significance, VRE power plants need communication interfaces to implement the advanced features required by the grid code. Active power management and power reduction for reserve provision purposes is especially relevant. However, gradient limitations and reactive power controllability all also necessitate dynamic control access by the system operator. While communication methods used in the past have been specific to vendor, modern power systems converge on communication channels based on international standards. One example is the ISO/ IEC 27000 series on information security management systems. Another is the IEC 61850 series on communication networks and systems in substations. A third is the IEC 62351 series on power systems management and associated information exchange - data and communications security.

Protection

Reliable operation of a power system always depends on the careful implementation of strategies that mitigate the impact of faults and other disturbances. Grid codes not only specify when generators need to remain connected to the grid during faults but also stipulate requirements of how the protection system at the point of connection shall be designed and which settings are to be used.

Contribution of Inertia

The fastest power reserves employed to balance sudden changes in load or generation usually need a few seconds before the reserve power is activated. It is essential that this delay be tuned to the maximum rate of frequency change expected in the system to limit the magnitude of any frequency excursion. Regardless of their power rating, converter-based VRE generators do not provide inertia. At a high instantaneous penetration of VRE generation, the remaining conventional generation from synchronous generators may not provide enough inertia. The rate of change of frequency might then be too high for the system to remain within the designated frequency limits in the case of the highest expected imbalance. This is a factor causing must-run conventional capacity in the system.

Black Start Capability

The ability to start a generation plant without any externally provided electricity is called black-start capability. Such power plants are the center from which the step-by step process of system energization sets off. VRE generator units alone cannot easily acquire black-start capability, although their primary power supply may be plentifully available at a time when this function may be needed. The main obstacle is the ability to perform effective frequency control and voltage control in an islanded system. Any method for implementing black-start capability with VRE generation would usually include a conventional generator or storage system capable of fast balancing.

Damping Power System Oscillations

As the rotating machines have a tendency for electromechanical oscillations, sufficient damping of these oscillations are necessary to maintain system stability. Therefore, VRE generator controls must be developed to damp certain oscillations in the system.

6.2.2 PHASES OF VRE INTEGRATION

The International Energy Agency (IEA) defines four phases of VRE integration, which are differentiated by the effects on power system operation resulting from increasing shares of annual VRE generation. As the effects of VRE become noticeable, operational practices can be upgraded and modified to integrate more VRE capacity and maintain smooth system operation [11].

1. Phase 1 – VRE’s share in annual electricity generation up to 3%; there is no noticeable effect on the system.
2. Phase 2 – VRE’s share in annual electricity generation around 3% to 15%; there is no noticeable effect yet and is manageable by upgrading some operational practices.
3. Phase 3 – VRE’s share in annual electricity generation around 15% to 25%; VRE poses significant impact and system operator can identify noticeable impacts. Operational changes must be introduced for system stability.

4. Phase 4 – VRE's share in annual electricity generation around 25% to 50%; VRE poses highly technical challenges for the system stability in very short time scales. At certain times, VRE may meet 100% of load so proper operational changes must be incorporated.

As the share of VRE in the generation mix increases, the technical requirements must also be modified, as summarized in Figure 9.

Figure 9. Technical Requirements According to VRE Penetration Levels

Power system context	Technical requirements
Always needed	• protection, • power quality, • power reduction during over-frequency
Low VRE share	• communication • adjustable reactive power • constraining active power (active power management)
Higher VRE share	• LVRT including current contribution • simulation models
Very high VRE share	• active power gradient limitation • reduced output operation mode for reserve provision • synthetic inertia
Exclusive use of VRE	• stand-alone frequency control • full integration into general frequency control scheme • stand-alone voltage control • full integration into general voltage control scheme

Source: "Getting Wind and Sun onto the Grid: A Manual for Policy Makers." IEA.

6.3 RECOMMENDATIONS FOR HARMONISED ASEAN GRID CODE

These recommendations are based on the information available from ASEAN member states grid codes and documents referred under sources section.

As suggested in "Establishing multilateral power trade in ASEAN by IEA", a stepwise voluntary development of multilateral trading from the existing bilateral trading is recommended. This model allows countries to make rapid progress on power system integration by completing ASEAN Power Grid, while allowing each country to make its own decisions on how it participates in regional multilateral trading. There is no requirement that each individual country participate in all the various trade models, if and when they are developed. These models are also designed to be compatible with one another, so that it will be possible for more than one model to exist simultaneously. The proposed models are as follows.

- As a near-term step, it is recommended that ASEAN establish a framework to support harmonized bilateral trading models by developing a set of standardized bilateral contract templates, a standard wheeling charge methodology, and a regional coordinator institution. This would allow countries to enter into bilateral trading agreements with any other AMS, regardless of whether they share a border. While this does not fulfil the broader goal of establishing multilateral power trading, it would improve the efficiency of bilateral trading in the region while also laying the groundwork for more formal multilateral trading.
- A secondary trading model should then be developed, which involves a regional market that exists separately from national markets and system operations. This would build upon some elements established in the harmonized bilateral model, such as harmonized wheeling charges, and introduce new elements such as a regional market operator and a central clearing party.

- Finally, an advanced primary trading model is proposed in these countries could choose to replace their national markets with a fully integrated regional market. This would bring additional benefits to participating countries but would also require more changes at the national level, including market restructuring.

The GMS RGC has been progressed in the Working Group on Performance Standards and Grid Code (WGPG) under the RPTCC. Considering the groundwork laid through extensive multilateral cooperation at the GMS level, it is recommended to facilitate the participation of ASEAN-level authorities (such as HAPUA) in the process so that the necessary harmonization of grid codes and regulations of Indonesia, the Philippines, and Malaysia also can be started.

The minimum technical requirements for VRE integration can be adopted in the regional code for uniform and coordinated development of the region. The implementation must account for the phases of VRE in each country. When the penetration of VRE in the various regions increase, the benefits of both increased interconnection and regional market frameworks become increasingly relevant where the trading of electricity products can be done closer to real time.

Other technologies such as Battery Energy storage system (BESS) and pumped-storage hydropower plants can manage excess supply of VRE generation, especially as the penetration levels increase. Advanced sensory and communication equipment can facilitate improved monitoring, visualization, and enhanced situational awareness of the regional grid events on real time. Furthermore, it will enable implementation of Wide Area Protection & Control Systems, which will improve grid reliability, reduce probability of blackouts and minimize their impact.

As countries advance their power sector restructuring (such as Vietnam), additional measures like Intra-Day Market (IDM) functions can be introduced to bridge the gap between day-ahead and real-time markets. In regions where the share of VRE is growing, the role of the IDM is increasing in importance because the IDM allows for rebalancing of positions as more accurate forecasts of VRE output become available.

In summary, the current GMS RGC process must progress. In the current phase, detailed specifications for various aspects of harmonized grid code have been developed based on ENTSO-E model. The technical and market gaps identified must be further investigated and discussed between TSOs at multilateral workshops to establish consensus. Countries must continue to develop their national technical framework and institutional improvements to make their grid secure and stable, in order to facilitate uptake of higher penetration of VRE and achieve regional integration more seamlessly.

ANNEX A: COMPARISON OF GRID CODES

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
Connection Policies		MINISTRY OF INDUSTRY AND TRADE - No .: 25/2016 / TT-BCT REGULATING ELECTRICAL DISTRIBUTION SYSTEM						
Demand Connection Policies	The Connection Code specifies the acceptable technical design, and operational criteria, which must be complied with by any Party connected to the grid	Specified - comprehensive: Responsibilities of the Unit that national electric system, level control moderation Responsibility of Customer in use of the electricity network Planning, maintenance and repair of the network responsibilities.	Not Specified	Not included in the code	Connection code for Renewable Energy Generation Plants, includes guidelines for Connecting Renewable Energy Generation Plants to PLN's Distribution System code with an installed capacity of less than 10 MW, connected to 20 kV and below. Undervoltage tripping recommended.	The Renewable Energy (Technical and Operational Requirements) Rules 2011 outlines the rules for connecting renewable energy sources to the grid but does not set detailed technical requirements. It limits renewable generation units to 30 MW. The Guidelines on Large Scale Solar Power Plants (2016, revised in 2017), allows PV generators of 30 - 50 MW. LVRT May be required by distributor for units > 30 MW. PV generators are required to disconnect at 49.5 Hz and 50.5 Hz.		GMS code specifies frequency tolerance, requirements for active power and frequency control, voltage tolerance, voltage control and reactive power provision, short circuit, reactive power and protection, control, power quality, connection compliance and testing of demand facility.

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
Synchronously Connected Generators	The generator shall be capable of continuous active power within 49.5 to 50.5 Hz. Should be able to supply real and reactive power within the voltage variations as per given below: 230 KV: 245KV-207KV, 115KV: 123KV-103.5KV and generate active power within 0.85 lagging to 0.9 leading.	Requirement for connected Hydro & Thermal power plant >30 MW to stay connected to the system during system frequency excursions as follows: 46 Hz to 47.5 Hz - 20 seconds (Hydro only) 47.5 Hz to 48.0 Hz - 10 minutes 48 Hz to 49 Hz - 30 minutes 49 Hz to 51 Hz – Continuous 51 Hz to 51.5 Hz - 30 minutes 51.5 Hz to 52 Hz – 1 minute (Hydro: 3 minutes). Requirements for VRE wind and solar power plants as follows: 49 Hz to 51 Hz in the following modes: Uncontrolled - according to availability of primary energy source; Controlled - Governing in response to regulating command in less than 30 seconds and following to +/- 1% of rated power. Also, must comply with above frequency response requirements of Hydro and Thermal power plant. Also, above 51 Hz; must be able to reduce power at the rate of 1.0% of rated power per second.	Each Generating Unit must be capable of operating at its then current Capacity: 1) at any System Frequency in the range 49.5Hz to 50.5Hz, and any decrease in Active Power output at System Frequencies less than 49.5Hz but not less than 47Hz shall be no greater than pro rata with System Frequency. 2) at Connection Point any power factor between 0.9 lagging and 0.9 leading. In addition, each Generating Unit must be able to absorb/produce reactive power continuously as defined in its generation Capability Curve.	The generator shall be capable of continuous active power within 49.5 to 50.5 Hz. Should be able to supply real and reactive power within the voltage variations under normal conditions and generate active power within 0.85 lagging to 0.9 leading. Specifies frequency with stand capability, unbalance loading withstand capacity, speed governing system, excitation control system, Black start capability and fast start capability.	In Sumatera Grid code, Generators grouped in small (<30 MW), medium (30-100 MW), and large (>100 MW). In Jamali grid code- Generators grouped in small (<50 MW), medium (50-200 MW), and large (>200 MW).	Not specified	As per the draft grid code, all generating units must be capable of continuously supplying their rated active power output at the generating unit terminals within the System frequency range 49.5 to 50.5 Hz. Any decrease of active power output occurring in the frequency range 47.5 to 49.5 Hz should not be more than a proportionate decrease in the frequency	Depending upon the size and voltage the generator is categorized as A,B,C &D. Specified frequency tolerance, active power and frequency control requirements, voltage tolerance, voltage control and reactive power provision, fault ride through capability, protection requirements, system restoration, islanding and black start capability, connection compliance and testing requirements.

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
HVDC Connections	At present there are no HVDC connections. So connection requirements are not specified in the grid code	Not specified	Not Specified	At present there are no HVDC connections. So connection requirements are not specified in the grid code	Not specified	Not specified	At present there are no HVDC connections.	The size of HVDC system and DC connected power parks are categorized as A,B,C & D depending upon capacity and voltage of connection. Code specifies frequency tolerance, active power and frequency control requirements, Synthetic Inertia, Voltage tolerance, voltage control and reactive power provision, Fault ride through capability, Power oscillation damping requirements, sub synchronous torsional interaction damping requirements, short circuit contribution during faults, power quality, protection requirements, system restoration, islanding and black start capability and connection compliance and testing requirements

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
Asynchronously Connected (DC) Generators	Not Specified	Not specified - Also, read under VRE generator requirements	Active power control system must be able to decrease the electric power from 100% to 0% on a 10% per minute manner. When encountering low voltage fault, a connection requester's generator must not immediately disconnect itself from its power network system and stay connected for a certain period of time. V < 50% - 0.3 sec, 50% < V< 90%-2 sec, 90% < V < 110%-stay connected, 110% < V < 120%-1 sec, V > 120%-0.16 sec. To prevent islanding while there is no power supply at the power network system, a connection requester's generator must be capable to disconnect from the power network system within one second. After the disconnection, if the power network system resumes to its normal state, the connection requester's generator must be able to wait about 20 seconds to 5 minutes before re-connecting to the power network system. The operation must observe the IEC 60364-7-712 standards.	Not Specified	Not specified	Not specified	At present there is no grid code specific for asynchronous generators. Ministry of Foreign Affairs and Trade, New Zealand provided technical standards framework document to Ministry of Energy and Electricity, Myanmar. It has references to the connection requirements for asynchornous generators which was provided as reference guide for new utility scale solar power plant producers.	Same as HVDC connections

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
Operational Policies/Codes		Specified - comprehensive			Not specified	Not specified	The draft grid code has part 4 which is operation code. It addresses operational demand forecast, outage planning, system services , operational liason,contingency planning, operational testing,testing and monitoring of users plants and safety assurance.	
Operational Security	Operational security is specified in the various chapters of the grid code	Specified - comprehensive System Operator's duties and procedures for operations in emergency and for blackout/ system islanding, black start and restoration. Load control, rationing and load shedding.	The fault clearance times for faults on the Generator's equipment directly connected to the EGAT Transmission System and vice versa shall be 80ms at 500 kV, 100ms at 230 kV, 120ms at 115 kV and 69kV. EGAT shall also provide backup protection and these backup protections will be coordinated so as to provide proper Discrimination. The target performance for the protection Dependability Index shall be not less than 99.5 %.	Following 4 Operating states are specified.1) Normal state- Here Grid have sufficient operating margin, Grid frequency with in 49.5 HZ- 50.5 HZ. Voltage with in 95%-105% of nominal value. Transmission lines and substation equipment loading shall be below 90% of continuous rating. 2) Emergency state- When multiple outage contingencies and if following conditions exist, grid contingency reserve is not adequate, voltage at connection point outside of limit 95%-105%, overloading of transmission and substation equipment, weather disturbance and law and order problems that effects the operation of grid. 3) Extreme State- when proper measures are	Not specified	Not specified	As per the part 4 of the draft grid code, Transmission system operator shall operate the grid securely under most severe single contingency.	Transmission system is classified as five states, Normal, alert, emergency, black out and restoration. Tso shall perform contingency analysis in every 30 minutes. Operational Security code for transmission system specifies system states, frequency control management, voltage control and reactive power management, short circuit current management, power flow management, contingency analysis and handling, protection and dynamic stability management.

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
				not taken in Emergency state can lead system into cascading outages, islanding or voltage collapse. 4) Restorative state- If generating units, transmission lines and equipment are bring back to synchronism and making back system to normal state. The operating criteria to maintain system in normal state and operational responsibilities are specified in the code.				
Operational Planning and Scheduling	Not Specified	Responsibility of the Unit that national electric system, level control moderation:- Plan, the operation modes serve the regulation and operation of electricity transmission system under control for years, months, weeks and days. Operates transmission system under control compliance provisions in Regulation electricity transmission system. Also, system operator undertakes market operation and generation/ ancillary services dispatch. Safety management. Also, operation of network communications; System Control And	They have monthly, annual and 5-year operating program. Normally, EGAT uses N-1 design criteria for planning and operation. In some circumstances which may cause cascade tripping on generating units, transmission lines or even system separation. To prevent the serious problem after N-2 incident EGAT preserve the right to install the protection system such as Automatic Generation Shedding if it necessary. The Operating Margin comprises Dependable Reserve, Available Reserve, Quick-Start Reserve, Spinning Reserve and Area Control Reserve. On the	The operational planning time frames are based on Three year, Annual, Monthly, weekly and daily. The next day schedule shall be issued by 15.00 (3.00 PM) everyday based on the generator availability. The grid security and reliability are required to be based on Single Outage Contingency criterion. During grid restoration into normal state, the grid needs to have self-sufficient island grids to be resynchronized. The grid also must have black start and fast start generating units at strategic locations. The grid operation and maintenance program	Not specified	Not specified	operational planning and scheduling is addressed in the part 3 of the draft grid code for TSO(Transmission system operator). (Part 3 of the proposed grid code is planning code)	Defines minimum operational planning and scheduling. All TSO shall develop individual grid models for merging to a common regional grid models in different time frames Year ahead, month ahead, week ahead, day 1 and intraday considering different scenarios. Each TSO shall conduct operational security analysis in different time frame by simulating each contingency from the list to determine healthiness of the system. Each outage coordinating TSO shall coordinate outage planning process within its responsibility area. Each TSO shall monitor availability of Ancillary Services. Each power

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
		Data Acquisition (SCADA) system. Constant exchange of information with grid users. Scheduling and coordination of testing.	first day of each of Calendar Year each Generator will provide EGAT, in writing, with a provisional Outage Program for Calendar Years 1 to 7.	time frames are based on every three year, annual, monthly, weekly, and daily. In addition, if there is any Significant Incident has transpired on the grid, the Significant Incident Notice shall be issued within 15 minutes from the occurrence and possible consequences have to be identified and required corrective measures are to be undertaken by respective stakeholders in the system. The Generation Scheduling Procedure includes hourly grid demand with system loss in the Grid, merit order table and followed by additional generating units to meet the Operating Margin required. The Generation Scheduling Procedure includes hourly grid demand with system loss in the Grid, merit order table and followed by additional generating units to meet the Operating Margin required.				generating facility and Demand facility shall ensure that scheduling agent is appointed. Generation schedule, consumption schedule, internal trade schedule and external trade schedule shall be prepared.

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
Load Frequency Control and Reserves	Not specified	Frequency governor requirements according to international (IEEE) standards. Reserve capacity scheduled by SO for each powerplant. Specified SO's Duties and authorities: Yearly, Monthly, Weekly & Daily Operating plans/ schedules prepared by system operators. System operations.	A System Frequency of 50Hz shall be maintained utilizing the Automatic Frequency Control Computer System owned and operated by EGAT.	Not specified The grid frequency is controlled by Frequency Regulating Reserve, Contingency Reserve and Demand Control methods. While the methods are well-defined and well-represented, there should be indicative values or range of values for the reserves as this could have impact on when initiating Load Shedding procedures under Demand Control method. Generating units needs to continuously regulate the active power supplied to the Grid. The units must implement fast-acting speed governing system to handle frequency control under normal operating condition. If there is any exemptions to the speed-governing system requirements, these exemptions should be specifically mentioned in the connection agreement.	For RE power generation- Remote controllability required from wind turbines, ramp rate limit for PV. For synchronous generators -Governor for primary control, Automatic Generation Control (AGC) connection for large and medium generators are considered.	AGC connection required	Part 4(Operation code) of the draft grid code specifies the operating reserves required for secure transmission grid.	The Countries which signed agreement to participate in Load frequency control by providing reserve will make effort to fulfill FRCE target parameters of the Load Frequency Control Block by involving in Frequency Containment Process, Frequency Restoration process, Reserve Replacement process, imbalance netting process, cross-border FRR activation process and cross border RR activation process. This is achieved by monitoring the system state by the synchronous area monitor

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
Emergency Response and Restoration	Contingency planning is specified in the chapter 7 of the grid code	Multiple system states: Normal operation mode, and: Operating in a warning mode: Insufficient regulating reserve/ Transmission line loading near limits/ System overvoltage/ undervoltage condition / Natural disaster or national defense emergency. Emergency mode: Operating outside one or more permissible ratings. Extreme emergency : Overloading to failure of a component/ Management of emergency has failed. 5. Restoration mode VRE must ride through: V < 0.3 pu - 0.15 sec 0.3 pu < V < 0.9 pu - Slope = T(min) = 4 x V - 0.6 0.9 pu < V < 1.1 pu - continuous operation 1.1 pu < V < 1.15 pu - 3 seconds operation 1.15 pu < V < 1.2 pu - 0.5 seconds operation	1)A Under Frequency Emergency shall occur when the System Frequency falls non-transiently to or below 49.25Hz. 2)A Partial Blackout occurs when a section of the System becomes disconnected from the remainder of the System, forming a Power Island. 3) A Total Blackout occurs when all Generation has ceased and there is no electricity supply from External Interconnections. Restoration - 1) Arrangements shall be made whereby, in a System Emergency, Load can be shed in Load Shedding Blocks. 2)Under Frequency Automatic Load Shedding shall be effected by the operation of Under Frequency Relays. 3) The settings on the Under Frequency Relays shall allow for Load Shedding in steps. 4) Load restoration 5)AUTOMATIC GENERATION SHEDDING 6) Black Start Capability.	Load shedding and emergency procedures are mentioned in the Chapter 5 of the grid code	Not specified	Not specified	Part 4(Operation code) of the draft grid code specifies emergency measures to be taken during contingent events and the restoration process	The Code lays down minimum requirements for management of emergency, blackout and restoration states by coordinating GMS system in a common and coherent way. The system defense plan incudes system protection schemes like automatic under frequency control scheme, automatic over frequency control scheme, automatic scheme against voltage collapse and automatic disconnection scheme on loss of synchronization. System defense plan procedure includes frequency deviation management procedure, voltage deviation management procedure, power flow management procedure, assistance for active power procedure and manual demand disconnection procedure. Code defines restoration plan, reenergisation and resynchronisation procedure after a blackout.
Market Policies/Codes (Operational Aspects)		Set up for operating an electricity market and ancillary services market			Not specified	Not specified	Part 5 of the draft grid code (Market code) specifies the market policies.	

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
Capacity Allocation and Congestion Management	Not specified	Congestion forecasting/ generation run-back	Not specified	Not specified	Not specified	Not specified	Part 5 of the draft code discusses about congestion management	These guidelines are provided to enable non-discriminatory access to the respective transmission grid for the purpose of cross-border trade. The following issues are considered. Member states shall provide Available Transfer Capacity and Total Transfer Capacity for specific cross-border transmission path for long term and short term trading. Capacity calculation methodology is specified based on reliability margin , contingency and local system change etc.
Electricity Balancing	Not specified	Detailed - Specified SO's Duties and authorities in: Yearly, Monthly, Weekly & Daily Operating plans prepared by system operators. Procedures for operations in emergency and for blackout/ system islanding, black start and restoration. Load control, rationing and load shedding.	Not specified	Electricity balancing and scheduling is specified in the Chapter 5 of the grid code	Not specified	Not specified	Specified in the part 5 of the draft grid code(Market code).	The code establishes a set of technical, operational and market rules to govern functioning of electricity balancing arrangements. It set out rules for the procurement of balancing capacity, the activation of balancing energy and the financial settlement of balancing energy.
Forward Capacity Allocation	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified	No information available	Not specified

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
Metering Policy	Not specified	Not specified - metering spec is part of the PPA. Metering check is part of commissioning.	EGAT will access information on power and energy via telemetering or Automatic Meter Reading (AMR) System. The connector is required to install a Unit Monitoring Meter and auxiliary devices to store 15-minute interval data on power and energy. The requirement is effective for SPP Firm under the Regulation for Power Purchase B.E. 2550 onwards. All CTs and PTs shall have two cores for main and backup energy meter, also they must have accuracy class of 0.2s complying with IEC 60044 standard. All energy meters shall be 3 phase 4 wires measurement type, the accuracy class of all energy meters for active energy shall be 0.2s complying with IEC 62052-11 and IEC 62053-22 standards, and 0.5s for reactive energy. All energy meters shall be compatible with the equipment and software already installed in the EGAT System. The time of TOU energy meters shall be controlled	Not specified	Not specified	Not specified	Specified in the draft grid code	Code specifies the minimum technical, design and operational criteria, accuracy and calibration, approval, certification and testing, meter reading and data management etc for the metering at the point of interchange of energy between control areas. Metering is capable of measuring the following parameters in both import and export directions. MW, MVAr, MWh and MVArh. This metering equipment will be the primary source of data for TSOs to operate AGC systems in real time and to account for inadvertent deviations . Main and check metering shall be provided from separate CT and VT windings. Three single phase CT's and three single phase PT's of Accuracy class 0.2 shall be used. Meter shall be three element type wit accuracy class 0.2 or better and shall comply with IEC Standard 62052-11. Meter should be calibrated in every 3 years and CT and PT every5 years.

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
			(synced) to be in limit very close to standard time, by using time synchronization signal from the Global Positioning System (GPS) clock receiver (standard time source) installed at metering site.					
Operator Training Policy	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified	Not Specified	The code contains Training programs, inter TSO training, training organization and despatchers accreditations and basic requirements of dispatcher simulator etc for the operation of GMS interconnected system
Technical Elements Required				Not specified	Not specified	Not specified		
Principles and Harmonized Technical Standards		Not Specified		Not specified	Not specified	Not specified		

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
Operating Voltage Range per Voltage Level	Nominal voltage: 230KV, 115 KV, 22KV 230 KV: 245KV-207KV 115KV: 123KV-103.5KV 22KV: 24KV- 19.8KV	Normal High Voltage is 220 kV Extra High Voltage system is 500 kV. Normal operation is rated voltage +/- 5%. Emergency operation is rated voltage +/- 10%	Nominal voltage: 500KV, 230KV, 115 KV, 69KV Normal: 95-105% of Nominal Voltage Emergency: 90-110% of Nominal Voltage	Nominal voltage: 500KV, 230KV, 115 KV, 35KV, 22KV Normal: 95-105% of Nominal Voltage Emergency: 90-110% of Nominal Voltage	Permissible voltage range in the grid for: RE power generation- +5%/-10% Vn For synchronous generators - ±5 % Vn for 500 kV, +5/-10%, Vn for 20-150 kV	The Malaysian Grid Code:±5% Vn for 500 kV, ±10% Vn for 275 and 132 kV, ±6% Vn below 132 kV. The Malaysian Distribution Code:+10%/-6% Vn for LV, ±5% Vn for MV and ±10% Vn at contingencies.	Nominal voltage: 500KV(under construction in four phases) , 230KV, 132 KV, 66KV. The voltage at any point on the Transmission System will normally remain within ±5 % of the nominal value. During abnormal conditions ±10%, but voltages between +5 % and +10 % will not last longer than 30 minutes.	0.9 pu to 1.118 pu- Unlimitted time 0.85 pu to 0.89 - 60 Minutes 1.118pu-1.15pu- To be specified by each TSO.

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
Correction Time for Frequency Deviation	47.0-47.5Hz, 20sec. 47.5-52.0Hz, Unlimited	Nominal frequency in the national power system is 50 Hz. Under normal conditions, the power system frequency is within ± 0.2 Hz of the nominal frequency. Where the electrical system is not stable, the system frequency is fluctuated within ± 0.5 Hz of the nominal frequency.	If System Frequency falls, not transiently, to or below 49.25Hz and no specific Instruction to the contrary is issued within 1 minute, then all Generators shall increase the output of their Synchronized Generating Units, either manually or automatically. If System Frequency rises, not transiently, to or above 50.75Hz and no specific Instruction to the contrary is issued within 1 minute, then all Generators shall reduce the output of their Synchronized Generating Units, either manually or automatically, by a minimum of 2% of Generating Unit output per 0.1Hz deviation from Target System Frequency. In case that the frequency at the interconnection point is not between 47.00 Hz – 52.00 Hz, the converter system must disconnect from the power system within 100 ms.	Under frequency ride through till 47.0Hz <5sec. Over frequency ride through till 52.0Hz <5sec	Not specified	Not specified	Not Specified	As per Frequency Quality Defining Parameters, Standard Frequency Range-±50 mHz, Maximum Instantaneous Frequency Deviation-800 mHz, Maximum Steady-state Frequency Deviation-200 mHz, Time to Restore Frequency-15 minutes.
Speed Governing System	Speed governor will be capable to provide power frequency response.	Governor systems specified in detail according to international norms. Power System Stabilisers (PSS) are a requirement.	For gas turbine Generating Units the governor must be capable of operating with a nominal droop characteristic of 4%. The	Speed governor will be capable to provide power frequency response.	Droop control, not specified for > 51.0 Hz Droop control, not specified for < 48.5 Hz Adjustable trip setting for RE generators.	Droop control 3-5%, May reduce output below 49 Hz, but must stay online. Speed governor recommended for synchronous units > 5	Governor systems shall, respond to frequency deviations exceeding ± 0.05 Hz, according to the requirements in part II (Connection Code)	Speed- droop characteristic of 2% to 12% . Frequency response settings for type A,B,C and D are provided.

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
			actual droop setting will be done by EGAT and the setting will not be changed without EGAT's approval.			MW, as per Malaysian Distribution code.		
Handling of Reactive Power Levels	Voltage limits are specified at point of connection	VRE power plants must contribute to management of voltage in the reactive power range + 0.9 pf/- 0.95 pf.	In the event of a sudden drop or rise in System Voltage must not increase or decrease Field Current until so Instructed by EGAT other than for reasons of safety, of either personnel or Plant.	Grid Voltage shall be controlled by synchronous generating units, Synchronous Condensor, Static VAR Compensators, Shunt capacitors and reactors and On load tap changing Transformers.	For RE power generation- Power factor should be controlled. For synchronous generators- Automatic Voltage Regulator (AVR) is recommended.	AVR, must meet the specifications provided by system operator. Voltage control from PV generators is neither required nor allowed. AVR for generators > 5 MW, otherwise 0.90 lagging unless otherwise specified, as per Malaysian Distribution code.	Voltage limits are specified at point of connection	Power-generating facilities shall be designed and capable of staying connected to the network and operating within the range of 0.9 to 1.1 pu of the nominal network voltage at the connection point. The synchronous power-generating facilities shall be equipped with a permanent automatic excitation control system that can provide constant alternator terminal voltage at a selectable setpoint without instability over the entire operating range of the synchronous power-generating module. Reactive power capabilities of different generating facilities are specified.
Operational Procedures		Detailed - Specified SO's Duties and authorities in: Yearly, Monthly, Weekly & Daily Operating plans/ schedules prepared by system operators. System operations.			Not specified	Not specified		

Type	Cambodia	Vietnam	Thailand	Lao PDR	Indonesia	Malaysia	Myanmar	GMS Standard
Control Areas and Control Block Co-ordination	There is no AGC in the system	Northern Region/ Southern Region - interface with regional distribution companies, large customers and large power plants	Not specified	AGC is specified in the grid code but is not in operational practice.	Not specified	Not specified	Not Specified	Specified
Frequency Control Standards	Nominal Frequency 50 Hz Normal- 49.5Hz-50.5Hz	Nominal frequency in the national power system is 50 Hz. Under normal conditions, the power system frequency is within ± 0.2 Hz of the nominal frequency. Where the electrical system is not stable, the system frequency is fluctuated within ± 0.5 Hz of the nominal frequency.	Nominal Frequency 50 Hz Normal: 49.5- 50.5 Hz. Emergency: 47-52 Hz	Nominal Frequency 50 Hz Normal: 49.5- 50.5 Hz.	For RE power generation- 47.5 – 51.0 Hz full output, For synchronous generators- 47.5 – 52.0 Hz online, 49.0 – 51.0 Hz full output.	The Malaysian Grid Code: 49.5 – 50.5 Hz full output, 47.5 – 52.0 Hz online, 10s at 47.0 – 47.5 Hz. The Malaysian Distribution Code: 49.5 – 50.5 Hz steady state, 47.0 – 52.0 Hz short term.	Nominal Frequency 50 Hz Normal: 49.5- 50.5 Hz. Emergency: 47-52 Hz	49.0Hz-51.0Hz - Unlimited 51.0Hz-51.5Hz- 30 mins 51.5Hz-52Hz-15 mins 47.0Hz-49.0Hz - To be specified by TSO.

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28. Vietnam Ministry of Industry & Trade Government Decree No: 39/2015 / TT-BCT Hanoi, November 18, 2015 CIRCULARS REGULATING ELECTRICAL DISTRIBUTION SYSTEM