A Guide to Operational Impact Analysis of Variable Renewables: Application to the Philippines

Australian AID
THE WORLD BANK
ESMAP
Energy Sector Management Assistance Program

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ABBREVIATIONS

DoE	Department of Energy
ERCOT	Electric Reliability Council of Texas
FRT	fault ride-through capability
HVAC	High Voltage Alternating Current
HVDC	high voltage, direct current
MW	Megawatt
NEM	National Electricity Market (Australia)
NGCP	National Grid Corporation of the Philippines
NREB	National Renewable Energy Board
NREP	National Renewable Energy Program
P&Q	Real and Reactive Power
PV	photovoltaic
RE	renewable energy
RES-E	renewable energy sources for electricity
VRE	variable renewable energy
WPP	wind power plant
WTG	wind turbine generator

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SUMMARY

This document serves as a guide for those wishing to investigate the impacts of variable renewable energy[1] (VRE) on the operation of power systems, particularly in the Philippines.

The work was commissioned by the World Bank in 2011 to enhance the understanding of power system operation issues most affected by the integration of VRE, based on international experience. The objective is to build capacity in the Philippines for determining the important issues for the national grid and to enable the Philippines to design, carry out, and interpret the results of appropriate and effective studies.

The approaches presented in this guide are based on state-of-the-art international practices, adapted to suit local conditions in the Philippines. The guide was developed through a survey of international VRE integration studies, charting the relevance to the Philippines of key elements such as the physical structure of the power system, the energy mix, expected level of VRE penetration, market structure, and operation practices and standards. These elements were then consolidated through discussions at a stakeholder workshop in Manila, which included the National Renewable Energy Board (NREB) and the National Grid Corporation of the Philippines (NGCP).

The Step-by-Step Study Guide

The study guide shows how to estimate the amount of VRE that can be integrated into the power system if no changes are made to its present configuration; however, more important, it shows how to determine the potential operational impacts if a certain percentage of renewable energy resources are to be integrated. The main modeling approaches, data requirements, and scenarios that need to be analyzed to assess different types of impacts are described, and are supported by summaries of relevant international experience and key reference studies.

Issues Relevant to the Philippines

Based on international experience, it was found that, although the issues most relevant to a power system depend on its unique characteristics (such as its size, the geographical distribution and expected installed capacities of the variable renewable resources, the system's operation scheme and market structure, the size of the balancing area, and interconnection capacity), certain issues receive more attention than others, as can be seen in figure 1. In particular, with higher amounts of VRE in a system, the complexity of balancing supply and demand, maintaining power system stability, and planning for long-term reliability is increased. However, these issues can be studied with existing power system analysis tools, and VRE growth can be managed simultaneously with integration studies, even to such high instantaneous penetration levels as 50–80 percent, as seen in Spain, Denmark, and Ireland. A critical precondition for the smooth transition into a high renewable energy future is effective planning based on robust system design, especially for market design, operational procedures, grid infrastructure, and regulatory performance requirements.

For small, weakly interconnected, island systems like those in the Philippines, certain issues are apt to be more relevant than others, particularly those issues relating to system voltage stability and frequency control. However, because the amount of variable renewables currently installed in the Philippines is low (less than 1 percent

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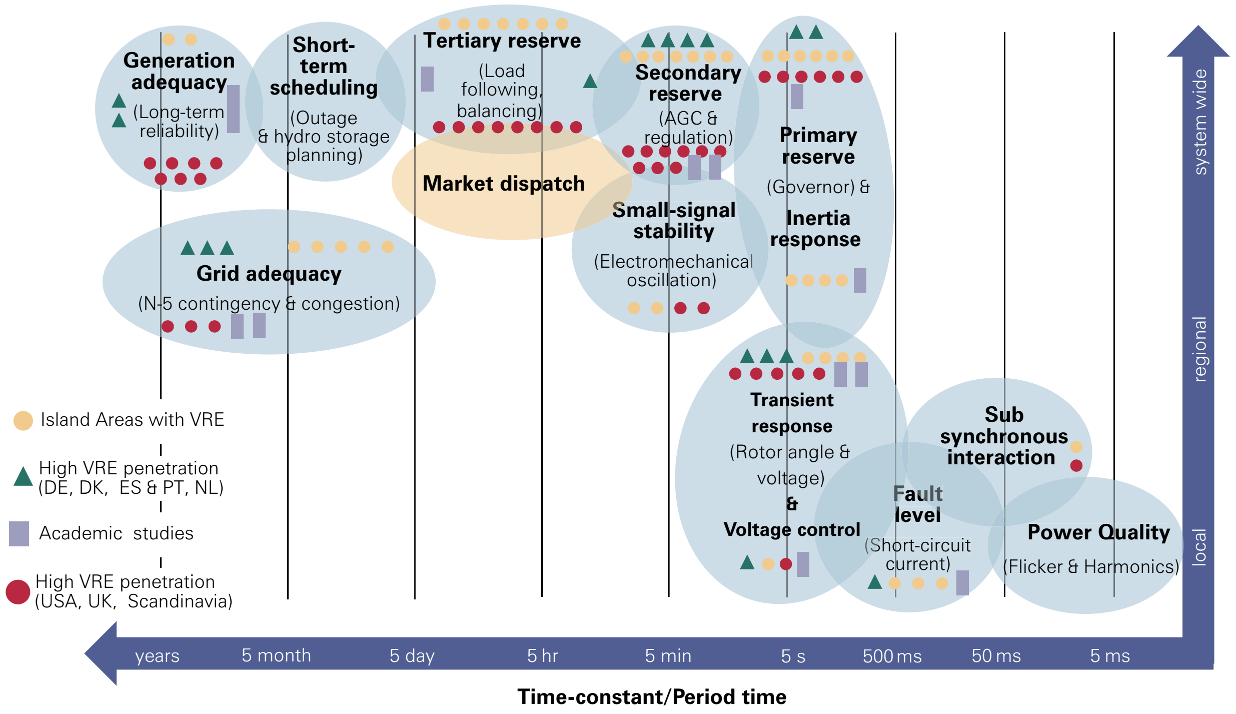
[1] Variable renewable energy includes wind, solar, run of river hydro, and ocean energy.

Figure 1. Issues Assessed in VRE Integration Studies Around the World



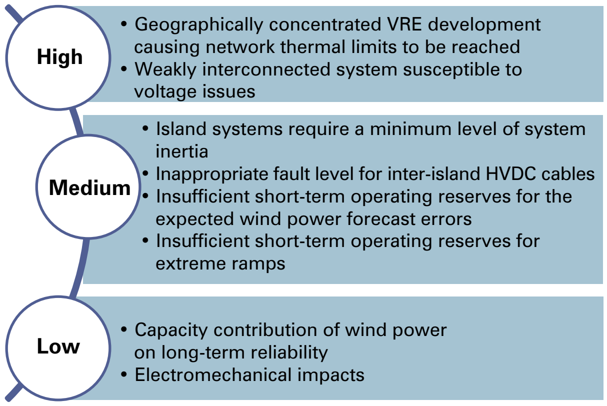
Source: Authors.

instantaneous penetration) in comparison with other systems around the world, there is still time to plan ahead. Therefore, it is recommended that potential impacts be studied now, while the penetration level is low, so that issues can be identified and addressed ahead of time. By learning from other systems with higher penetration levels and building a robust and adaptable system for future integration of variable renewables, it will be possible to accommodate renewables and make a smoother transition to a reliable future system.

Based on the characteristics of the Philippine power system and information available in the public domain, the issues listed in figure 2 were identified as being particularly relevant. They are ranked as:

- ***High:*** items that are relevant now and should be assessed promptly;
- ***Medium:*** items that could be an issue for island systems and should be considered in the future when higher penetration of VRE is expected: and
- ***Low:*** items unlikely to be immediate issues but that could be incorporated into long-term planning when higher penetration levels are expected.

Figure 2. Issues that Can Set Limits for VRE Penetration for the Philippines



- Geographically concentrated VRE development causing network thermal limits to be reached
- Weakly interconnected system susceptible to voltage issues

- Island systems require a minimum level of system inertia
- Inappropriate fault level for inter-island HVDC cables
- Insufficient short-term operating reserves for the expected wind power forecast errors
- Insufficient short-term operating reserves for extreme ramps

- Capacity contribution of wind power on long-term reliability
- Electromechanical impacts

Source: Authors.

Detailed step-by-step procedures for evaluating the issues ranked as high and medium are presented in this report; general guidelines are provided for those items ranked as low.

It must be noted that the analysis is based on a literature survey; therefore, to gain a thorough understanding of the issues and their implications, actual system operators should be consulted.

Key Messages

The future penetration level of VRE in the Philippines will depend largely on the feed-in tariff and Renewable Portfolio Standard policies currently being developed by the government. However, given the decreasing capital costs of wind power and solar photovoltaic (PV) technologies, and the short lead time required to build these generation assets, rapid expansion is a possibility, and the pace of growth of these technologies may vary among the islands.

The question that then arises is, how can the possible impacts on the electric power system be investigated if maximum VRE penetration depends on the power system itself? International experience shows that the VRE penetration level depends not only on the physical system design but also on its operational procedures. Both of these factors have large degrees of freedom, and by redesigning the system or changing the detailed operational strategy, penetration levels can be significantly increased. Hence, the grid integration study methods in this report do not determine system limits but will lead to recommendations for upgrading the power system or changing its operations.

Much of the wind power development is expected to occur in Luzon; therefore, higher VRE penetration levels will be experienced there before in the other two grids. This indicates that studies focusing on Luzon should be conducted more thoroughly, and more immediate solutions may need to be implemented. For instance, most wind power developments are planned for the north of the island, and energy will have to be transferred via transmission lines to the demand center in Manila. Thus, the transmission capacity of the system would need to be analyzed to ensure that thermal and voltage limits are respected.

Visayas is connected to Luzon with a high-voltage, direct current (HVDC) interconnector and is expected to have the second largest development of wind and solar power. The grid is unique in that it consists of a number of interlinked small islands, rather than being on a single island like Luzon and Mindanao. As with Luzon, the impact of new generation on transmission capacity adequacy and voltage limits would need to be analyzed, as would be the impact on fault levels, particularly at the terminals of the HVDC interconnector, to ensure that levels remain adequate for correct operation.

Although its plans for wind power development are modest, the Mindanao grid is currently a self-contained island system with limited reserve capacity, and is in need of additional generation capacity. The construction of an interconnector to Visayas is being considered, which would alleviate some of the stress on Mindanao's system. However, the details are yet to have been worked out, and it is unclear to what extent such an interconnection might contribute to the reserve requirement.

Despite studies showing adequate reserves in the Luzon and Visayas grids until about 2020, the operational reality in the Philippines suggests there could be much less flexibility as a result of contract conditions on the provision of regulating reserves. Therefore, it is urgently recommended that contractual agreements impeding regulation capability of the power system be revised.

An analysis by the Philippine Department of Energy (DoE 2011) estimates that approximately 50 percent of the additional generation capacity needed to meet future reserve requirements in the Philippines must be mid-range and peaking generation. Modern wind turbines and solar PV inverters can provide some of the features of these types of generation, indicating that growth in flexible wind and solar PV power would be highly desirable.

Thus, it is imperative that the responsible parties in the Philippines adopt a forward-looking planning approach and explore the possibilities for integrating variable renewable energy. The issues to be examined in determining the best development path for the Philippines include the level of VRE that can be managed with existing operational capabilities, the changes that may be required to accommodate higher penetration levels, and the associated costs.[2]

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[2] Note that this report does not provide guidance for determining the economic impact of technical solutions.

1. INTRODUCTION

The Philippines is facing energy challenges similar to those in many other countries. The main challenges are the need to build energy infrastructure to deal with growing power demand; maintaining adequate reserves for droughts and their impact on hydro resources for power generation; developing strategies to deal with climate change and meeting international expectations to reduce greenhouse gas emissions; coping with rising fossil fuel prices; and enhancing energy security by making better use of indigenous renewable resources.

These factors have led the Philippine government to issue policies that promote the development of local renewable energy (RE) for power generation. In 2008, the Congress of the Philippines enacted the Renewable Energy Act (RA 9513, in this report referred to as the RE Act), which aims to accelerate the exploration and development of RE use in the Philippines, including biomass, solar, wind, tidal, wave, and geothermal, in on-grid and off-grid systems. As established in the RE Act, incentives such as feed-in tariffs and a Renewable Portfolio Standard are under development, and are expected to encourage the growth of all eligible RE sources, including variable renewable energy (VRE).[3]

Exactly how much VRE can be integrated into the Philippine power system, and whether a maximum limit needs to be imposed to ensure the security and reliability of supply, are overarching issues. The National Renewable Energy Board (NREB), the National Grid Company of the Philippines (NGCP), and other stakeholders are investigating ways to assess the impacts that the system may experience in dealing with growing amounts of VRE, and whether certain maximum limits need to be set until the system is upgraded or operational procedures are amended to take into account higher shares of VRE.

As with other countries, the concern in the Philippines is that high levels of RE could cause additional complexities due to its variable nature. These concerns mainly revolve around balancing operations, power system stability, and reliability. However, the findings from many VRE integration studies from the European Union and the United States are that

- VRE impacts can be studied with existing modeling tools;
- VRE growth can be promoted while integration studies are conducted;
- high penetration of VRE can be managed (as proven by experiences in Spain, Portugal, Ireland, and Denmark);
- a robust transmission design and grid code procedures and VRE technical requirements are vitally important; and
- the most suitable solutions for VRE integration issues can vary depending on power system characteristics.

This report thus attempts to provide information to aid the Philippines in determining how to study the operational impacts of VRE so that a maximum penetration limit, if any, can be found.

The results are presented as a "how to" guide, which recommends a series of necessary steps for assessing the impacts of VRE on the Philippine power system and determining the maximum penetration level of VRE, where possible.

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[3] The term used in the RE Act is "intermittent RE resources, and to include wind, solar, run-of-river hydro and ocean energy."

The guide first identifies and describes the types of issues often considered relevant for VRE integration, based on a broad review of VRE integration studies across the globe (section 2.1 and appendix B). The relevance of these issues to the Philippine power system is then assessed through a review of publicly available information about its characteristics (section 2.2). Based on this assessment, suggestions are made about which issues might be most relevant for the Philippines (section 2.3). Finally, recommendations are given for studying the issues identified as having potentially high impacts, as well as for interpreting the results (section 3).

The step-by-step study guide in section 3 describes the main modeling approaches, data requirements, and scenarios to analyze to identify the impacts of different levels of VRE penetration. It also indicates the results that should be expected and how to interpret them, and provides recommendations on which stakeholders to engage in the study. Key references are also provided.

Although best efforts have gone into the analysis, it is based on a literature survey. Therefore, to gain a thorough understanding of the issues and their implications, actual system operators and relevant industry stakeholders should be consulted.

2. VRE INTEGRATION STUDIES

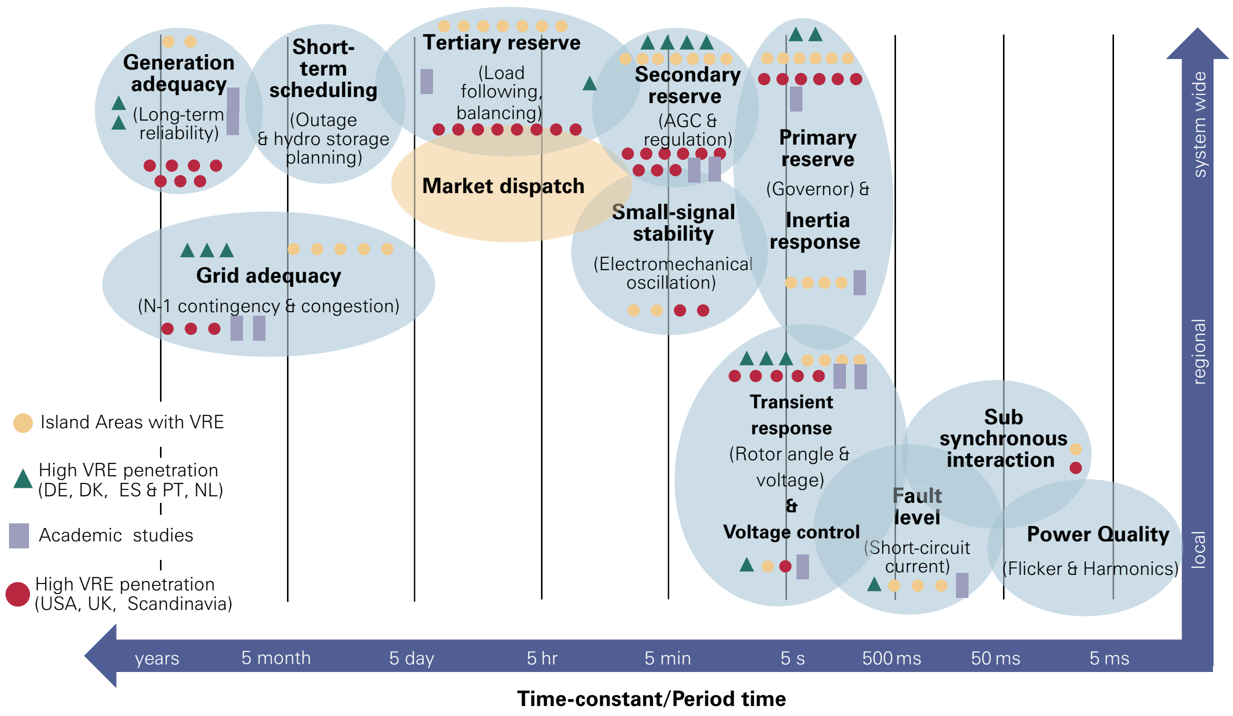
2.1. Issues Examined in International Variable Renewable Energy Impact Studies

With the use of wind power for electricity generation growing around the world, the impact of wind variability on power system operation has been a popular topic of study (see figure 2.1). Experience thus far shows that more challenges arise under the following conditions:

- when the share of power delivered by wind in the generation mix is relatively high; and
- when wind power is added to systems that are weakly interconnected.

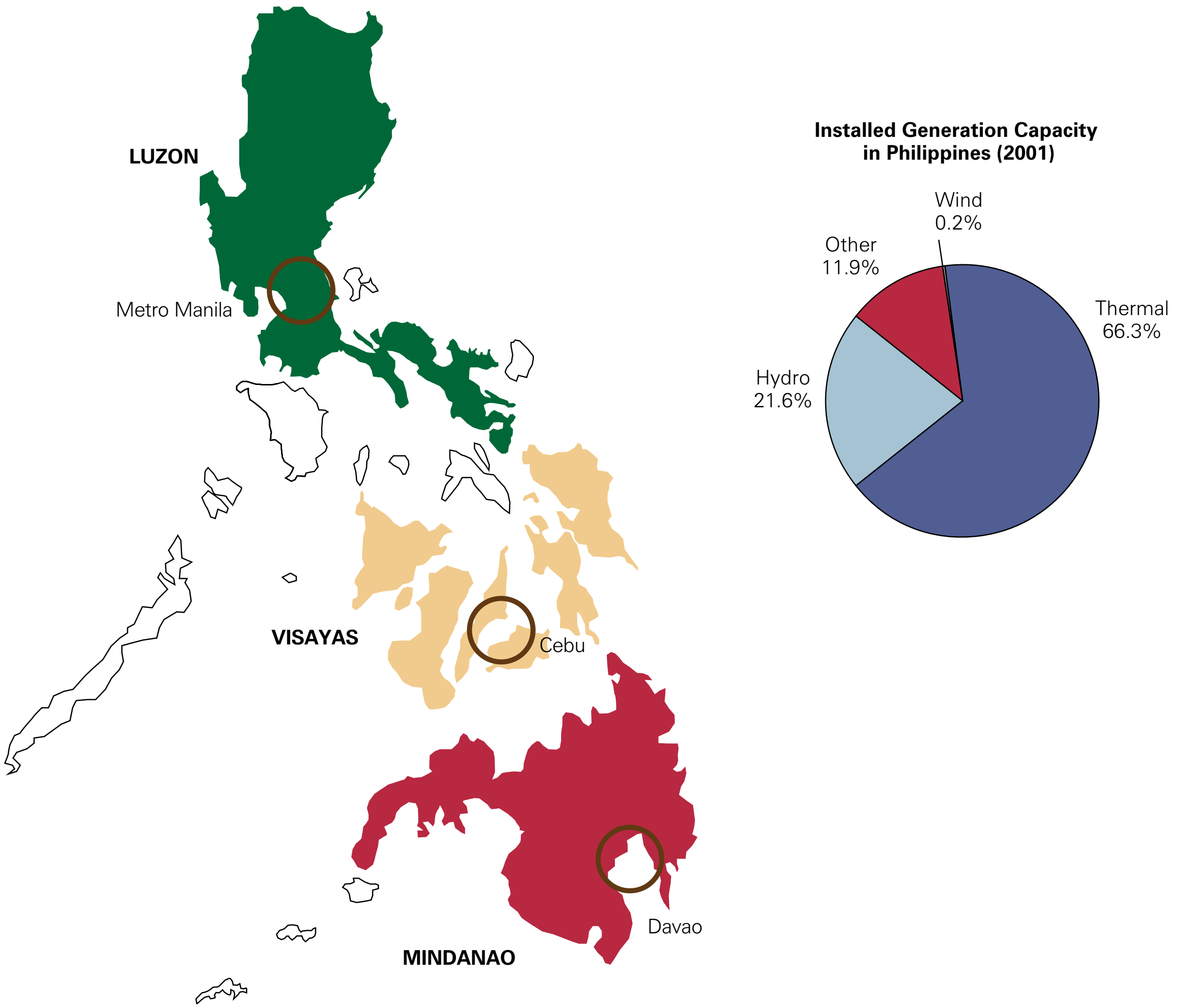
For this report, studies from leading nations in wind power integration, such as Denmark, Germany, Spain, and Portugal, were reviewed, as were studies from countries

Figure 2.1. Issues Assessed in VRE Integration Studies around the World



Source: Authors.

Figure 2.2. Map of Interconnected Regions of the Philippines, with Energy Mix and Demand Centers

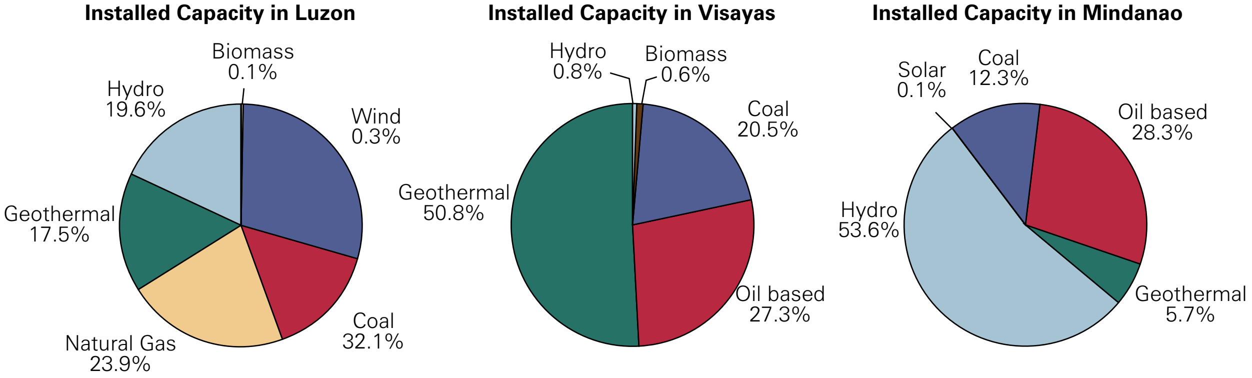


Note: Modified from [1] slide 1 and [2] page 55.

showing strong growth and significant research activities, such as Ireland, the Scandinavian countries, the United Kingdom, and the United States. In addition, power systems with the following characteristics similar to those in the Philippines were reviewed:

- systems that are already short in reserves, such as that operated by the Electric Reliability Council of Texas (ERCOT);
- relatively small and islanded systems, such as those in New Zealand and Tasmania;
- systems with a generation mix or other important factors for managing variability with some similarities to the Philippines, such as in New Zealand, the National Energy Market in Australia, the New York Independent System Operator, and ERCOT; and
- small island systems such as those in the Caribbean and Hawaii.

Figure 2.3. Installed Generation Capacity Mix in 2010 for the Philippines



Source: Graphs produced by authors based on information from Table 1.

2.2. Characteristics of the Philippine Power System

The power system in the Philippines consists of three grids: Luzon, Visayas, and Mindanao (figure 2.2). Electricity production in each region varies somewhat, with coal-, oil-, and natural-gas-fired generation in Luzon; geothermal, coal, and oil in Visayas; and mainly hydro and oil in Mindanao (figure 2.3). A high-voltage, direct current (HVDC) interconnector links the Luzon and Visayas grids; Mindanao is a self-contained island system.

The installed generation capacity, dependable capacity,[4] and peak demand of the three main grids in 2010 are shown in table 2.1.

Based on the Department of Energy (DoE) information, the currently installed generation capacity appears to be sufficient to meet peak demand, even without transfers

Table 2.1. Generation Capacity and Peak Demand in MW for the Philippines in 2010

System	Luzon		Visayas		Mindanao		Philippines	
Peak demand	7,656		1,431		1,288		10,231	
Generation capacity	Installed	Dependable	Installed	Dependable	Installed	Dependable	Installed	Dependable
Total generation	11,981	10,499	2,407	1,744	1,970	1,658	16,358	13,901
Coal	3,849	3,531	786	501	232	212	4,867	4,244
Oil based	1,984	1,586	615	464	594	438	3,193	2,488
Natural gas	2,861	2,756	0	0	0	0	2,861	2,756
Geo-thermal	899	500	964	751	103	100	1,966	1,351
Hydro	2,346	2,101	13	13	1,040	907	3,399	3,021
Biomass	9	5	29	15	0	0	38	20
Wind	33	20	0	0	0	0	33	20
Solar	0	0	0	0	1	1	1	1

Source: [2] page 55 and [3] page 17.

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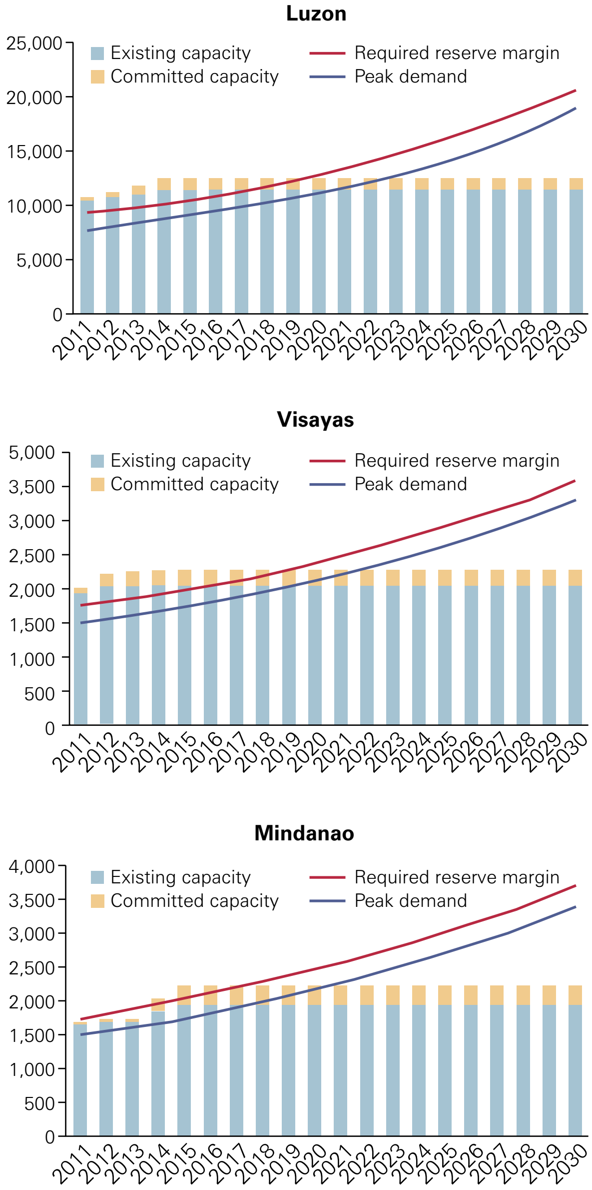
[4] For long term planning purposes, the DoE defines dependable capacity as the maximum capacity a power plant can sustain over a specified period modified for seasonal limitation less the capacity required for station service and auxiliaries (NGCP 2011).

between the grids. However, projections (figure 2.4) suggest that a tight demand-supply situation could develop during the next decade unless new generation enters the system to supply the growing demand. In Luzon and Visayas, supply may be insufficient to cover the required reserves in about 2020, whereas in Mindanao, supply appears insufficient to secure reserves even now.

Figure 2.4. Demand-Supply Projections for Luzon, Visayas, and Mindanao, Assuming Only Committed Projects are Built Between 2011–30



Source: [1] slides 6, 8, and 10.

These figures clearly indicate that additional investments, on top of the generation capacity currently under construction and committed, are required to meet demand by 2020 and beyond. Furthermore, despite indications of adequate reserves in the Luzon and Visayas grids until about 2020, the operational reality in the Philippines requires ensuring flexibility through adequate ancillary services arrangements.

The Department of Energy (DoE 2011) projects that additional generation capacity of about 1,500 MW will be required in Luzon by 2020, and by 2030, an additional 10,450 MW. Similarly, Visayas will require an additional 450 MW by 2020 and 2,000 MW by 2030; and Mindanao will require a further 750 MW by 2020 and 1,950 MW by 2030. Moreover, approximately 50 percent of the capacity should be mid-range and peaking generation (DoE 2009); therefore, growth in wind and solar photovoltaic (PV) power would be highly desirable.

VRE in the Philippines

As defined in RE Act, variable renewable energy (VRE) sources include wind power, solar PV power, ocean power, and run-of-river hydro power schemes. Currently, the only VRE installed in the Philippines is wind power,[5] at just over 33 MW, solar PV at 1 MW,[6] and run-of-river hydro. Several run-of-river schemes have been developed in the past decades and have been operationally adequately managed; the focus of this report on VRE will be on wind power and solar PV. Compared with many other countries, these two sources represents an insignificant amount of VRE (figure 2.5).

As a proportion of total installed generation, the penetration of wind power in the Philippines is still relatively low (table 2.2). Countries with high penetration of wind power, measured by both proportion of total installed capacity and proportion of total electricity production, are mostly based in Europe, led by Denmark, Portugal, Spain, Ireland, and Germany.

The potential for economically exploitable VRE resources has been reported in Elliott and others (2001); Renne, Gray-Hanne, and others (2000); Renne, Heimiller, and others (2000); and DoE (undated); and the locations

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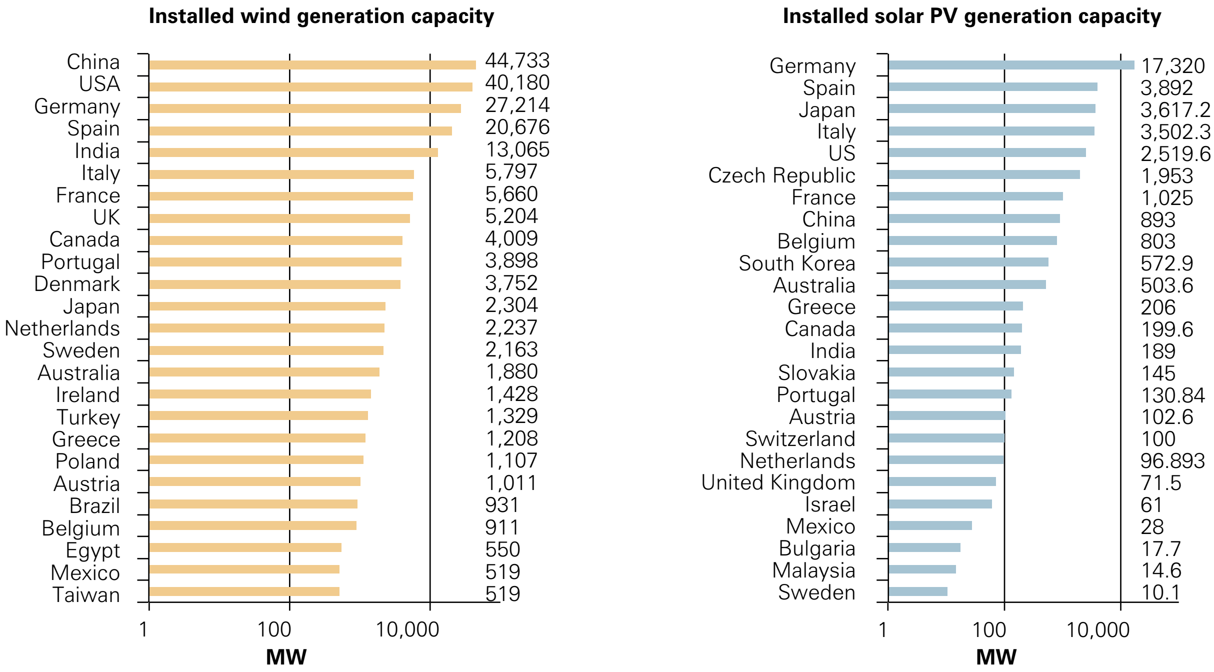
[5] There are also run-of-river hydro schemes but no data specific to this technology were available to the authors.

[6] Cepalco's 1 MWp photovoltaic power plant (http://www.cepalco.com.ph/solar.php).

Figure 2.5. Installed Wind and Solar PV Generation Capacity at End of 2010 (MW)



Source: GWEC for wind data and BP [4] for solar data.

are marked in figure C1 (wind), figure C2 (solar), and figure C3 (ocean) in appendix C. Substantial plans for expansion exist for wind power generation at the moment (appendix C). The government plans are to triple the existing installed renewable energy capacity of 5,438 MW by 2030 according to the 2011 Transmission Development Plan published by NGCP (2011). The National Renewable Energy Program (NREP) for 2011–30 produced by the Philippine DoE is extracted from this document and summarized in table 2.3.

Table 2.2. Comparisons of Percentage of Wind Power to Total Installed Generation Capacity and Percentage of Wind Power Production to Total Electricity Production for Philippines and Top 10 Countries in 2010

	% wind power/total installed generation capacity		% wind power/ total electricity production	
Ranking	Country	%	Country	%
1	Denmark	28.9	Denmark	21.3
2	Portugal	20.7	Portugal	18.0
3	Spain	18.4	Spain	15.3
4	Germany	16.9	Ireland	10.5
5	Ireland	13.4	Germany	6.5
Philippines	**Rank 42**	**0.2**	**Rank 36**	**0.1**

Source: WWEA, IEA, ENTSO-E.

Table 2.4 shows the potential VRE power penetration for each grid in the Philippines. This metric more accurately portraits the potential challenge for power system operators to maintain balance between demand and generation. In a conventional power system, power balance is normally maintained by tracking a variable demand with a predictable and dispatchable generation supply. However, when the energy source itself is fluctuating, managing supply becomes difficult, especially without accurate forecasting of the VRE. The higher the component of uncertainty, the higher the complexity and resources required to deal with the dispatch process. Therefore, for system operators and reliable supply, the penetration rate of VRE relative to demand is most important. The worst case scenario is when demand is at its minimum and wind farms are generating at maximum installed capacity).

Table 2.4 shows that the expected amount of wind power development in the Philippines could lead at certain hours to penetration rates of 15–25 percent, specifically

Table 2.3. Renewable Energy Capacity Addition in the Philippines

	Installed Capacity (MW)					% VRE/total generation capacity (2030)
Sector	2010	2015	2020	2025	2030	
Geothermal[a]	1,966	2,186	3,286	3,381	3,461	11.0
Hydro[b]	3,399	3,740	6,901	8,793	8,793	28.0
Biomass	38	315	315	315	315	1.0
Base load renewables	5,403	6,241	10,502	12,489	12,569	40.1
Wind	33	1,081	1,936	2,378	2,378	7.6
Solar PV	1	270	275	280	285	0.9
Ocean	0	0	35.5	70.5	70.5	0.2
Variable renewables	34	1,351	2,247	2,729	2,734	8.7
Total renewables	**5,437**	**7,592**	**12,749**	**15,218**	**15,303**	**48.8**

a. Depending on the type of technology, it may not be controllable. If this is the case it needs to be categorized as variable renewables.
b. We have not separated run-of-river hydro although it should be categorized as variable renewable.
Source: Modified from: [9] page 91 and [1].

Table 2.4. Installed VRE capacity and penetration With and Without Interconnectors for the Philippines in 2010 and 2030

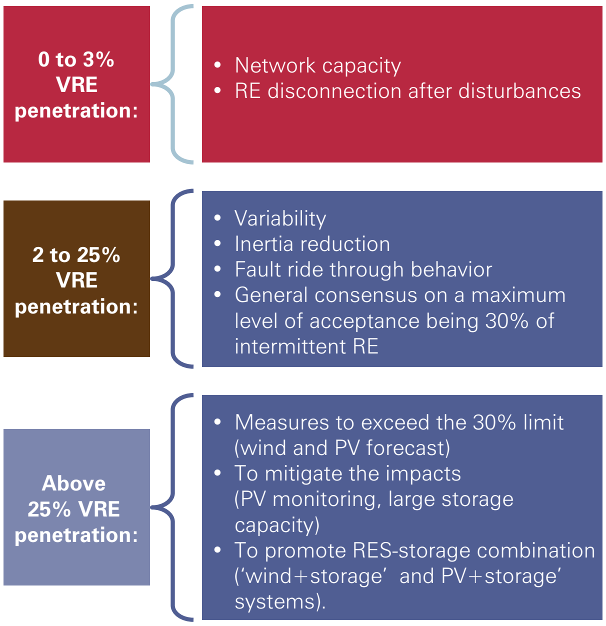
System	Luzon		Visayas		Mindanao		Philippines	
Year	2010	2030	2010	2030	2010	2030	2010	2030
Variable renewables (MW)	33	2,400	0	272	1	62	34	2,734
Interconnector ex-port capacity (MW)	150	150	440	440	0	400	–	–
Minimum demand (MW)	3,828	9,331	716	1,635	644	1,676	5,116	12,267
Instantaneous VRE penetration without interconnector[a] (%)	0.9	25.7	–	16.6	0.2	3.7	0.7	22.3
Instantaneous VRE penetration with interconnector[b] (%)	0.8	25.3	–	13.1	0.2	3.0	–	–

a. Calculated values: Installed wind capacity / Off-peak demand
b. Calculated values: Installed wind capacity / (Off-peak demand + Interconnector export capacity)
Source: [9] and [10].

in the Luzon and Visayas grids. These levels are moderate compared with other power systems in low demand–high wind conditions, such as in Texas (about 45 percent), Ireland (about 70 percent), and the Iberian Peninsula (about 100 percent). However, the operators of small, weakly connected island power systems like that in the Philippines should consider investigating some operational issues earlier, similar to those studied in Tasmania (15–30 percent), New Zealand (about 20 percent), and the islands of Hawaii (20–35 percent) because of the challenges associated with energy exchanges and sharing ancillary services across inter-island connections. The following guidelines provide a broad view of the issues significant for island systems at various penetration levels (Bayem 2011).

Operation and Reserve Requirements

The grid operating criteria in the Philippine Grid Code (approved by the Energy Regulatory Commission, 2011) states that the grid shall be operated so that it remains in the "normal state," even after the loss of one generation unit,



transmission line, or transformer. The normal state is classified as when

- the operating reserve margin is sufficient,
- the grid frequency is within the limits of 59.7 and 60.3 Hz,
- the voltage at all connection points is within the limits of 0.95 and 1.05 of the nominal value,
- the loading level of all transmission lines and substation equipment is below 90 percent of the continuous ratings, and
- the grid configuration is such that any potential fault current can be interrupted and the faulted equipment can be isolated from the grid.

Operation in the normal state, mainly refers to two concerns: controlling the frequency and the voltage within the stipulated limits. At all times, synchronized generation capacity must be sufficient to match the forecasted grid demand as well as to cover the operating margin (frequency regulating reserve and contingency reserve) necessary to ensure the power quality, security, and reliability of the grid. The types of reserves and their requirements are depicted in figure 2.6.

Although the current and expected VRE penetration rates are quite low compared with other power systems in the world, because the actual growth of VRE will depend largely on the success of the feed-in tariff and the Renewable Portfolio Standard (RPS) schemes being introduced by the Philippine government, it may be worthwhile to examine the conditions that could affect the speed of development. The following characteristics, however, indicate that some issues are expected to challenge the operation and planning of the power system as VRE penetration increases.

- The Philippine power system is a weakly interconnected series of islands.
- Economically sound wind power resources are available in the peripheries of the system.
- Studies already show that congestion is expected in Luzon because wind power development is concentrated in the north of the island, whereas demand is in the center and the south.
- Operational limits on the HVDC interconnection between Luzon and Visayas do not permit reserves to be transferred from one island to the other, even though Visayas is planned to become a single reserve zone. Thus, reserves are currently designed to be met locally on each island grid.

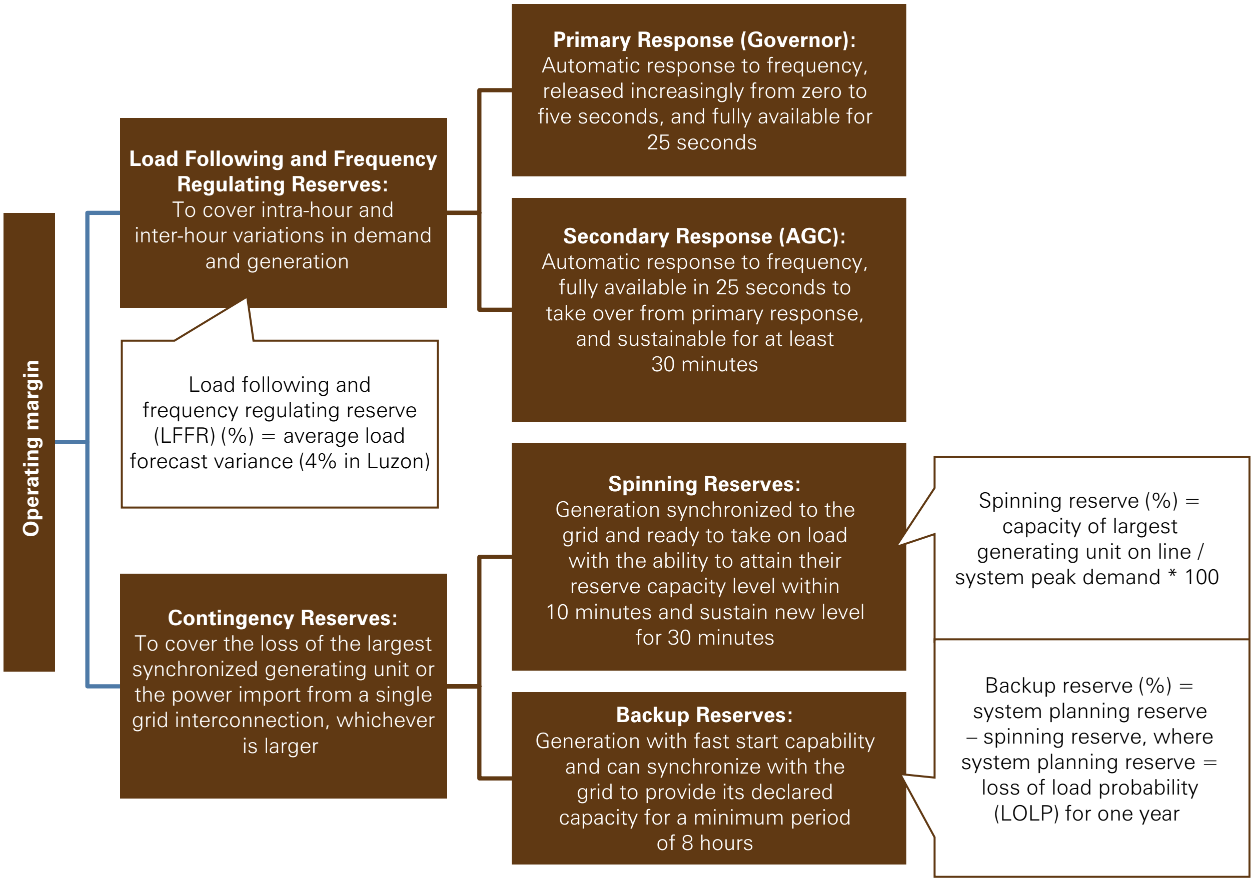
The limit on the amount of VRE that can be integrated into the system is expected to depend on the following issues.

Potential High Impacts

Issues that may have potentially high impacts are relevant now and should be assessed immediately (figure 2.7).

- ***Grid adequacy for steady-state operation:*** Injection of active and reactive power (P&Q) by new power plants changes power flow characteristics, potentially hitting static thermal and voltage limits, requiring permanent solutions such as grid upgrades. This is particularly a concern for Luzon because transmission is already constrained in some areas (NGCP 2009, 21), and will only be exacerbated by wind build-up in north Luzon.
- ***Grid adequacy for transient voltage response:*** Weakly interconnected systems are susceptible to voltage issues. The reactive power support capability of new VRE power plants may be insufficient to prevent voltage collapse, requiring the installation of external devices or implementation of operating limits.

Figure 2.6. Types of Reserves Defined by the Philippine Grid Code



Source: Graphic created by energynautics based on information in Grid Code [12] and WESM [13].

Potential Medium Impacts

Issues potentially having medium impacts are important for island systems with high VRE penetration (figure 2.8).

- ***Inertia and frequency response of island systems:*** System inertia may be insufficient to prevent frequency excursions that cannot be controlled by primary reserve. This is more likely for island systems with high VRE penetration.
- ***Fault level adequacy for HVDC operation:*** The short-circuit contribution of VRE power plants may create fault levels that are inadequate for the proper operation of inter-island HVDC cables.[7]
- ***Reserve adequacy for expected forecast errors:*** The method for determining secondary and tertiary (non-event) reserve requirements and ancillary services procurement arrangements (including the market structure for ancillary services) may be inadequate for expected VRE power forecast errors.
- ***Reserve adequacy for extreme ramps:*** The method for determining primary and tertiary (event) reserve requirements and ancillary services arrangements may be inadequate to handle weather-related VRE power ramps.

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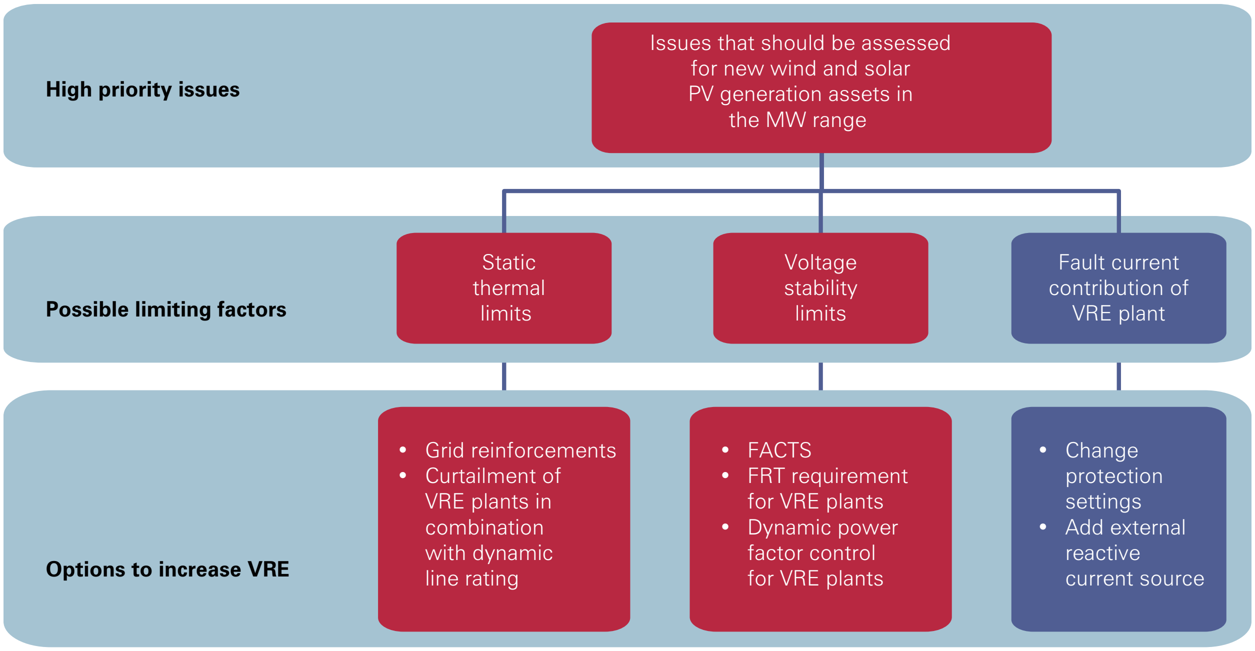
7. Currently, one HVDC link connects Luzon and Visayas. It has been in operation since 1998 and uses current sourced converter technology. An additional HVDC link is expected to be installed between Visayas and Mindanao grids in the future.

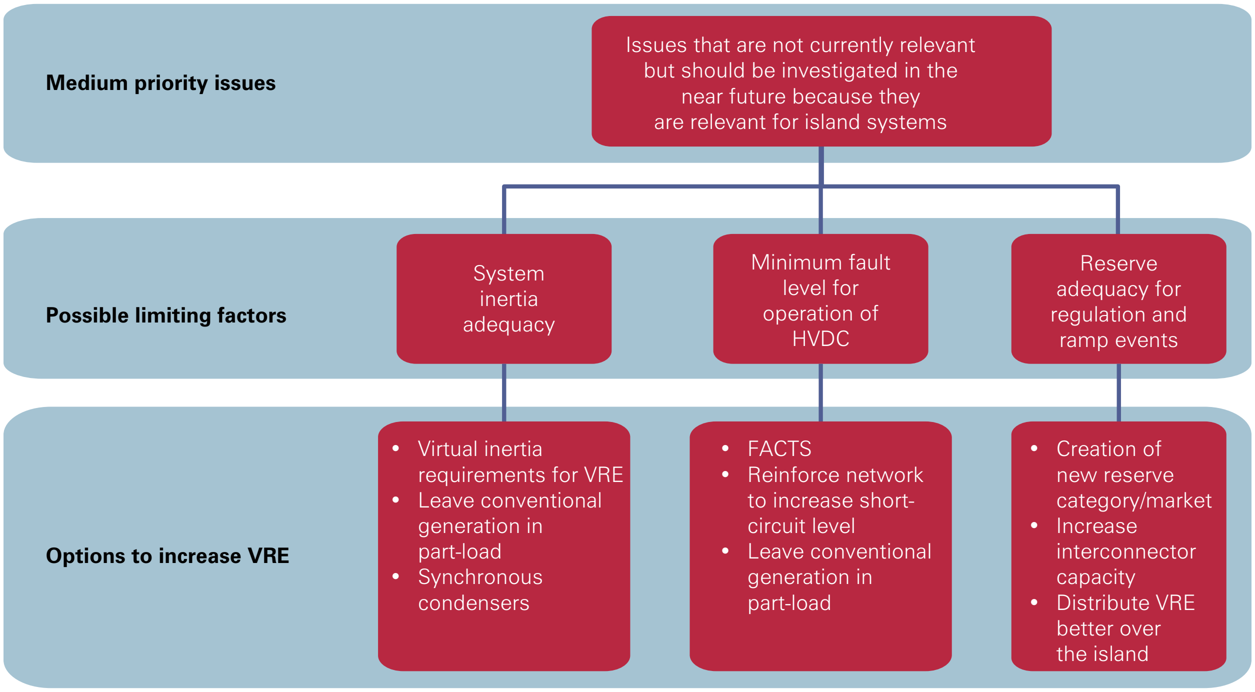
Figure 2.7. Flow Chart for High Priority Issues



Note: Connection studies for generators other than wind farms must cover the following aspects [45]: thermal assessment; voltage assessment; stability analysis (transient); fault current assessment; operational assessment (if necessary); protection assessment

Source: Authors.

Figure 2.8. Flow Chart for Medium Priority Issues



Source: Authors.

Potential Low Impacts

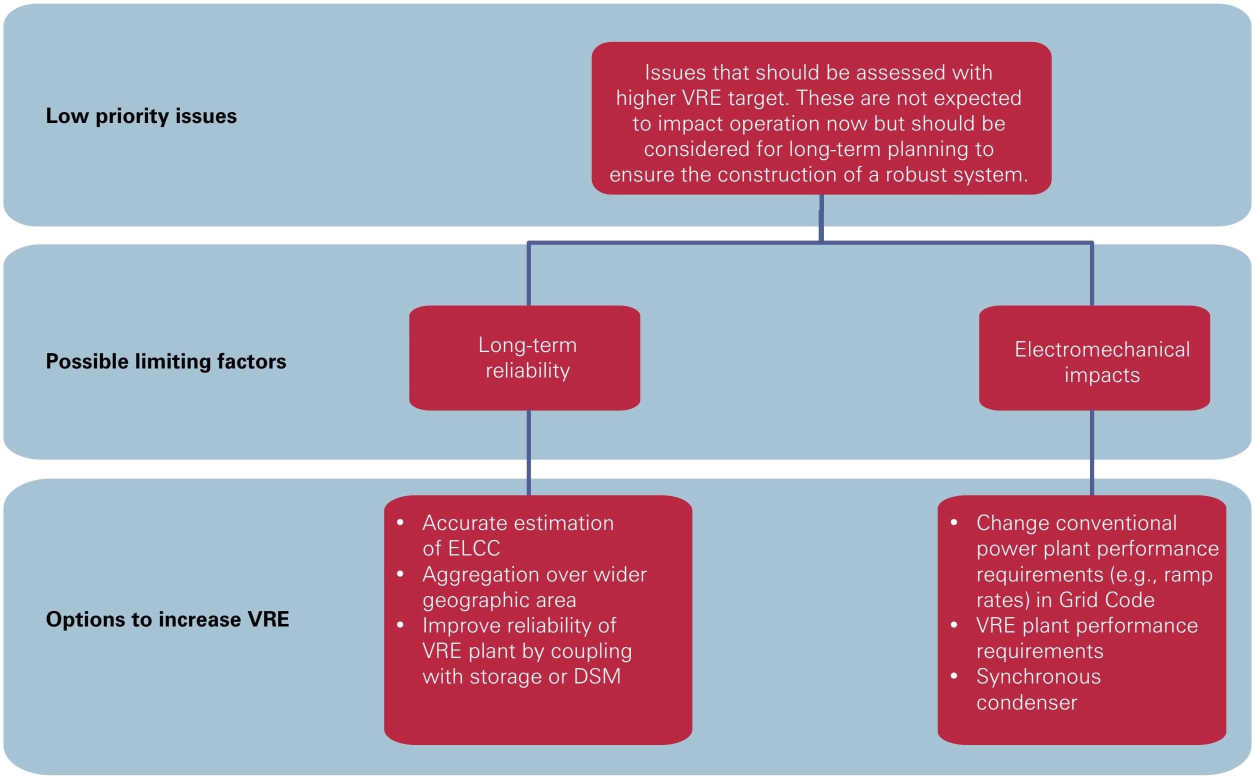
Issues identified as having low potential impacts are unlikely to become critical until extremely high penetration is imminent, but should be investigated to assist robust long-term planning (figure 2.9).

- ***Treatment of wind power in long-term reliability assessments:*** When VRE is added, the dependable generation capacity to meet supply reliability standards should be carefully assessed.
- ***Electromechanical impact:*** Inverter-connected generation displaces synchronous generation and reduces the ability of the system to control electromechanical stability. This occurs in response to large or small disturbances or to subsynchronous interactions.

Detailed step-by-step procedures for evaluating the issues ranked as high and medium are presented in this report; general guidelines are provided for the items ranked as low.

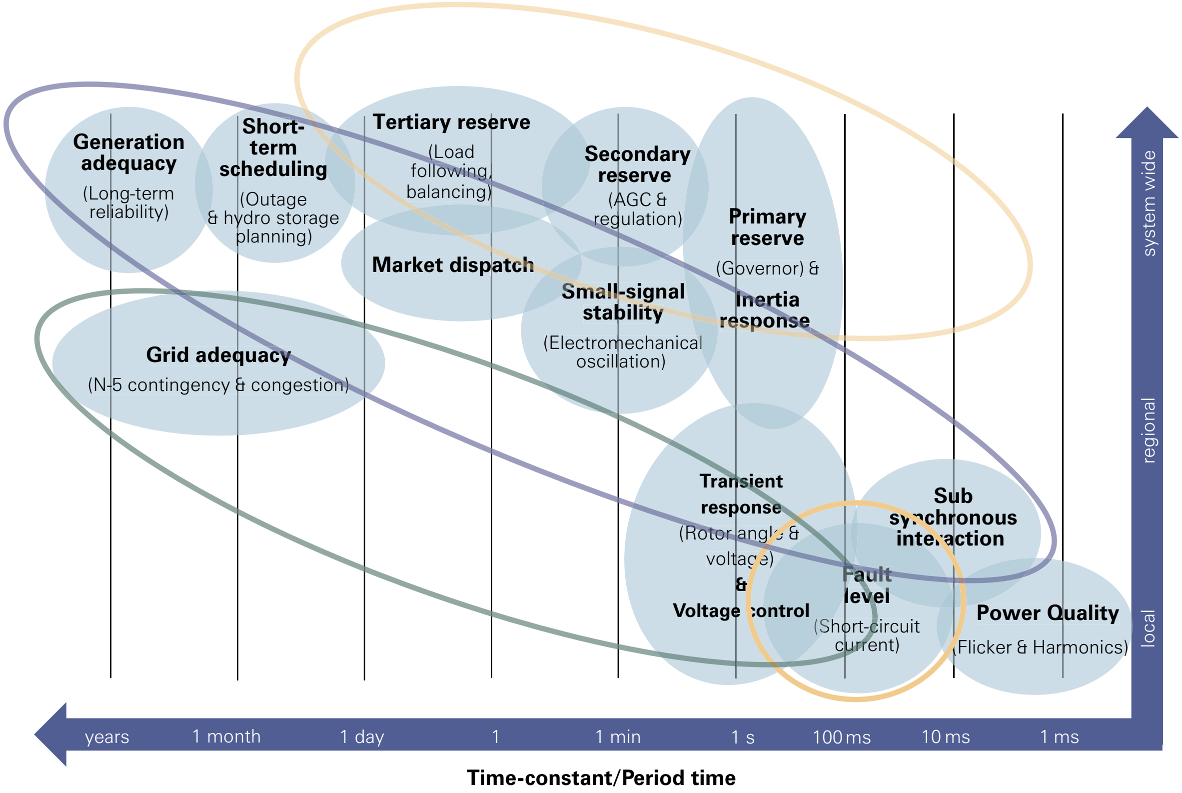
Figure 2.10 shows the recommended areas of study for assessing the likely impact of integrating VRE into the power system in the Philippines.

Figure 2.9. Flow Chart for Low Priority Issues



Source: Authors.

Figure 2.10. Priority Issues to be Investigated in the Philippines



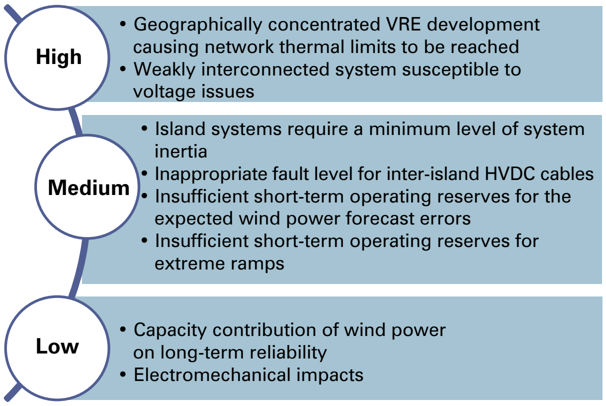
Source: Authors

3. STUDY GUIDE

This section gives step-by-step instructions for investigating the various impacts to determine whether limits to variable renewable energy (VRE) integration need to be set. The approaches introduced are based on international experience.

The issues that may become limiting factors for the Philippines are shown in figure 3.1. They are ranked as High: items that are relevant now and should be assessed promptly; Medium: items that could be an issue for island systems and should be considered in the future when higher penetration of VRE is expected: and Low: items unlikely to be immediate issues but that could be incorporated into long-term planning when higher penetration levels are expected. Detailed step-by-step procedures for evaluating the issues ranked as high and medium are presented in this report; general guidelines are provided for those items ranked as low.

Figure 3.1. Issues that Can Set Limits for VRE Penetration



Source: Authors.

3.1. Grid Adequacy for Steady-State Operation

The grid adequacy study investigates whether the addition of new generation assets causes power flow characteristics and active and reactive power (P&Q) loading on network elements to change outside static thermal and voltage limits. This is a standard study that should be conducted for any type of generation, not just renewables, and can be used to determine the maximum amount of VRE that could be integrated without breaching these limits. The report by Minnesota Transmission Owners (2008)[8] is a good example of such a study.

Most studies assess areas of the network that require reinforcement or augmentation to accommodate a certain amount of VRE (figure 3.2), rather than attempting to determine limits to the amount of integration. Because wind power plants (WPPs) are often located far from load centers and at the margins of the grid, and because less time is required to build wind and solar photovoltaic (PV) power capacity than to build transmission capacity, it is vital that this study be performed well ahead of time as part of long-term grid planning. This advance work will enable a robust power system to be designed and built, one that can adapt to a variety of potential renewable energy development scenarios.

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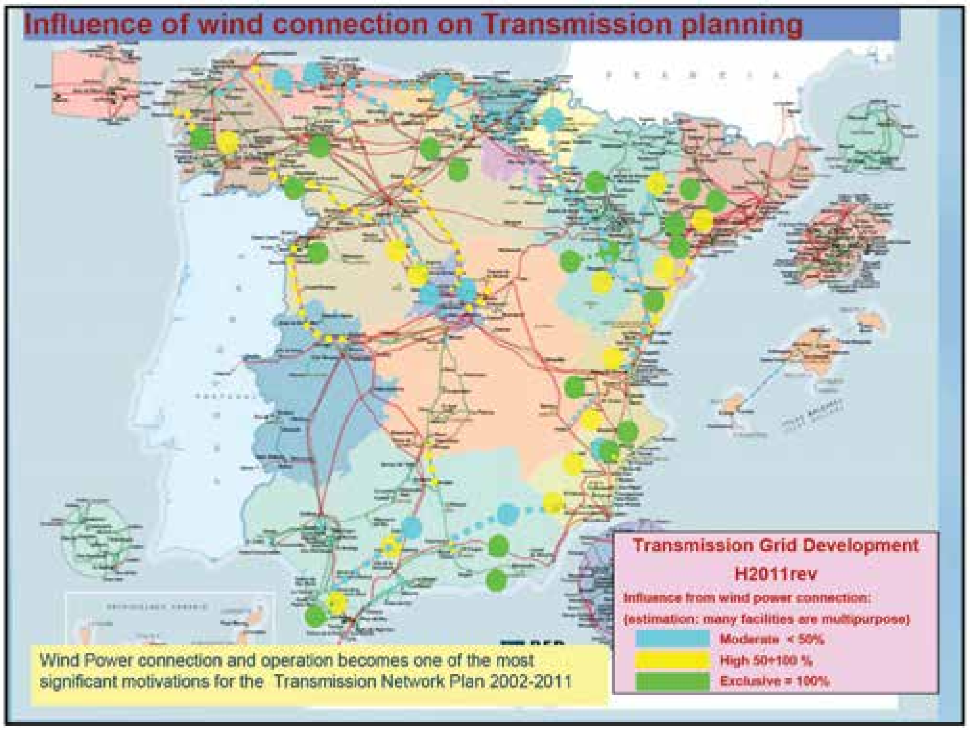
[8] For more information, see pp. 39–41 of that study.

Objectives	A) Maximum VRE penetration study To determine the maximum amount of VRE that can be integrated without violating static thermal and voltage limits. B) Identification of key infrastructure To identify key transmission infrastructure development that would be required to integrate high levels of renewable energy sources for electricity (RES-E) advocated by government policies.
Methodology	Based on a number of future generation scenarios depicting the diverse development possibilities for VRE in the Philippines, perform steady-state load flow analysis. A) Maximum VRE penetration study Apply future demand and generation availability scenarios (see **Scenarios** for details on setup of scenarios), starting with the maximum VRE output for each scenario. Study the power flows for (N) and (N–1) conditions to see if they result in any static limit violations. If a violation occurs, decrement the VRE generation output and study the power flow again. Repeat this process until no violations occur. B) Identification of key infrastructure Apply future demand and generation availability scenarios with the expected level of VRE dispatch under (N) and (N–1) conditions to identify areas that are likely to experience congestion; areas that are likely to experience over- or under-voltage issues; and areas of the network that will need to be extended. Based on the findings, infrastructure that will be required to accommodate the VRE in each scenario can be evaluated. These infrastructure changes may be in the form of (but not restricted to) transmission line upgrades, and flexible alternating current transmission system (FACTS) devices. Infrastructure common to all scenarios can then be identified as key solutions for integration of VRE. Additionally, the associated costs of each scenario can be calculated for comparison.
Scenarios	A number of generation scenarios should be studied to adequately capture the range of possible future developments in the following: installation area and capacity of wind and solar power, including existing plans and approved RE projects (for example, in a queue system) and based on political and economic assumptions (for example, fuel prices, carbon price, feed-in tariffs, technology price, government support schemes, and so forth); phasing out of conventional power plants; and delays to existing generation and transmission expansion plans. The ability of the transmission system to deliver power supply under "stressful" conditions should be assessed to identify where reinforcements may be required. Such situations typically occur during peak demand periods with high and low wind or solar power availability; off-peak demand periods with high and low wind or solar power availability; system contingencies (N–1); and periods with extreme weather, such as storms, based on an analysis of historical weather events. However, other situations might also be critical, depending on the power system.
Model requirements	**Philippine transmission grid:** AC power flow model with the existing topology and typical operation scheme (open breakers and so forth). **Wind power generation:** Aggregated P&Q output of WPP based on fixed wind speed for high and low wind power outputs. **Solar PV power generation:** Aggregated P&Q output of solar PV power plant based on fixed irradiance for high and low power outputs. **Other generation:** P&Q model with full availability corresponding to the time point analyzed, including external reactive power devices.
Data requirements	**Demand:** Projected future peak and off-peak demand for all nodes in network model (maximum and minimum demand in MW). **Generation:** Projected future installed generation capacity and corresponding availability during peak and off-peak periods.
How to interpret results and the expected output	If the simulation results in static thermal or voltage limit violations, a maximum VRE penetration limit may need to be imposed unless further measures are taken (such as increasing transmission capacity). Even if more VRE capacity is built, it will not be possible to transport it to demand centers. The energy will simply be curtailed. The most common solution for alleviating congestion is to upgrade the transmission lines to increase the active power-carrying capacity. However, in many cases it takes longer to build transmission lines, than it takes to build new WPPs and solar PV plants. Temporary solutions may be implemented, such as introducing dynamic line ratings or using phase-shifting transformers. Ultimately however, it is important to have a good understanding of the areas that are likely to be affected in the future and ensure a robust transmission planning process is in place that anticipates critical infrastructure for integration of the expected future VRE development. It is expected that congestion will exist in Luzon in any attempt to transport wind energy concentrated in the north of the island to the demand center in Manila. This has in fact already been observed (NGCP 2009, 21).

Figure 3.2. Example of Transmission Planning for VRE Integration in Spain



Influence of wind connection on Transmission planning

Transmission Grid Development

H2011rev

Influence from wind power connection:

(estimation: many facilities are multipurpose)

🟦 Moderate < 50%

🟨 High 50÷100 %

🟩 Exclusive = 100%

Wind Power connection and operation becomes one of the most significant motivations for the Transmission Network Plan 2002-2011

Source: [14] slide 22. http://www.google.de/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CDYQFjAA&url=http%3A%2F%2Fwww.feed-in-cooperation.org%2FwDefault_7%2Fdownload-files%2F2nd-workshop%2Fsession2alonso.pdf%3FWSESSIONID%3Dccdf1f3ce9cff60fc2ea590f0a7e5213&ei=zqtJUZqLFYPdPYHqgfAP&usg=AFQjCNFmVTH4-hOtylegICOQmaQtxyQ-uQ&bvm=bv.44011176,d.ZWU

Reference Study: Minnesota "Dispersed Renewable Generation Transmission Study"

This study was conducted to assess the possibility of accommodating 600 MW of dispersed renewable generation in the state of Minnesota. The state was divided into 42 sites across the five planning zones. The maximum amount of wind power that could be connected at each site with minimal impact to the transmission system was determined (see figure 3.3).

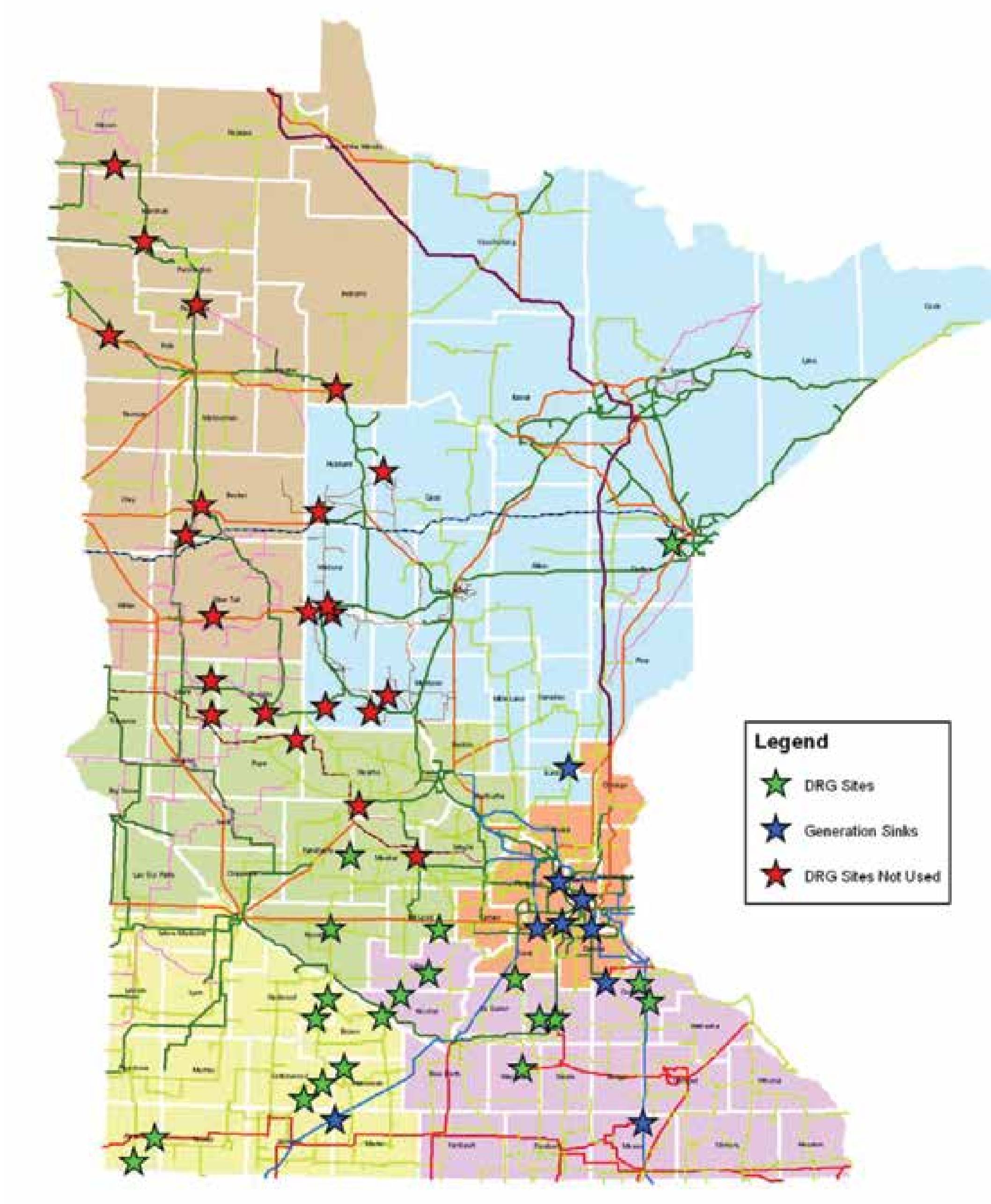
Step 1: Alternating current (A/C) steady-state analysis was conducted at each site for summer peak and summer off-peak models. The analysis was performed under the assumption that generation capacity would be added to only one site in the state and all other sites would be held to 0 MW. A comparison of two cases, with and without the wind power installations, allows identification of transmission facilities that are significantly affected by the addition of wind power. For the purpose of the study, the criteria for an overloaded transmission facility was 100 percent of its continuous rating limit for both system intact and N–1 contingency conditions. In addition to the base case (no wind power), 42 single sites were examined. The generation output at each site was initially set to 40 MW before system intact and contingency analysis was performed. The results were compared with the base case, and when an overload resulted, the case was rerun at 35 MW and decremented in 5 MW steps until an output level was reached at which no overloads occurred.

Step 2: Sites within a zone were aggregated and studied again for overloads. In each zone, the aggregated capacity was 225 MW. In a process similar to Step 1, the total wind power in a zone was decremented by 25 MW until no overloads resulted.

Step 3: Finally, a statewide analysis was conducted. All statewide facility outages were considered, as were those of facilities immediately adjoining Minnesota. From the steady-state analysis, 20 locations were chosen for wind power installation, and areas where grid augmentations might be required were identified.

Step 4: The 20 selected locations were tested for transient stability after critical regional faults. The impacts on the overall system and interconnectors were observed to see if faults affected regional system stability.

Figure 3.3. Map of Minnesota Electric Transmission Planning Zones with Final Distributed Renewable Generation



Source: [20] page 49. http://www.uwig.org/DRG_Transmission_Study_Vol_I_061608045236_DRGTransmissionStudyVolI.pdf

3.2. Grid Adequacy for Transient Voltage Response

This second grid adequacy study investigates whether the system can prevent voltage collapse upon the addition of new generation. This is a standard study that should be conducted for any type of generation, not just renewables, and can be used to determine the maximum amount of VRE that could be integrated without violating voltage limits. The Minnesota Transmission Owners report (2008)[9] is a good example of such a study.

Most studies assess the implementation of solutions to accommodate a certain amount of VRE, such as improving the grid code, using VRE power plants with improved voltage support capabilities, installing external reactive power support devices, and setting operating limits.

The amount of VRE that can be integrated is highly dependent on the fault ride-through capability (FRT) and reactive power support capability offered by the VRE power plants. Thus, it is important that the grid code require the new and existing VRE generation comply with requirements for supplying voltage support capabilities, and be accurately represented in the study.

Because of the resources it takes to perform voltage stability simulations, it is recommended that this study be performed after the reference study (3.1) to see if these voltage studies result in even more stringent requirements (see figure 3.4).

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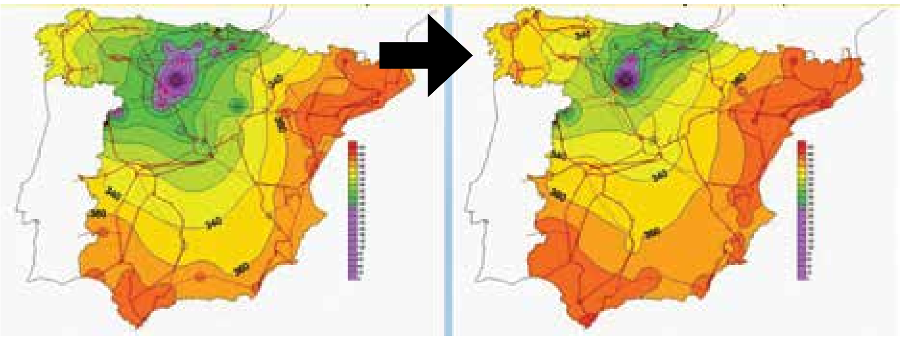
[9] For more information, see Minnesota Transmission Owners (2008, 38–40).

Figure 3.4. Example of Voltage Profile Improvement Due to Implementation of an Operating Measure in Spain



Source: [14], slide 50. http://www.google.de/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CDYQFjAA&url=http%3A%2F%2Fwww.feed-in-cooperation.org%2FwDefault_7%2Fdownload-files%2F2nd-workshop%2Fsession2alonso.pdf%3FWSESSIONID%3Dccdf1f3ce9cff60fc2ea590f0a7e5213&ei=zqtJUZqLFYPdPYHqgfAP&usg=AFQjCNFmVTH4-hOtylegICOQmaQtxyQ-uQ&bvm=bv.44011176,d.ZWU

Objectives	A) Maximum VRE penetration study To determine the maximum amount of VRE that can be integrated into the power system without violating voltage limits. B) Assessment of reactive power capability requirements To assess the level of reactive power capability required to integrate high levels of RES-E advocated by government policies.
Methodology	Voltage issues are generally local issues, therefore studies should concentrate on regions in which voltage problems are already known to exist. These regions are often where power transfer limits or load limits (or both) have been imposed on system operation. Based on the expected future system configuration, investigate the behavior of the system during and after low voltage conditions. Perform the investigation by applying future demand and generation availability scenarios and performing dynamic simulations of voltage dips caused by events such as short-circuit faults at the connection point of large WPPs and solar PV plants. Monitor the voltage at the connection point in time domain, covering the periods during and after the fault for about 20 seconds. A) Maximum VRE penetration study Starting with the most severe scenario, which is usually maximum VRE output and either maximum transfer or load depending on the voltage issue, check whether the voltage recovery characteristic complies with grid code requirements. If it does not, decrement the VRE generation output and study the voltage again. Repeat this process until no violations occur. B) Assessment of reactive power capability requirements Apply the most severe scenario as was done for the maximum VRE penetration study, and observe the voltage recovery. If there is a violation, place a fictitious reactive power compensation device at the desired point, and study the voltage recovery again. Based on this analysis, develop voltage support measures and assess their effectiveness. These may include stricter low voltage ride through or voltage support requirements for VRE power plants, installation of external voltage support devices, and implementation of operation restrictions. Additionally, the associated costs of each scenario can be calculated for comparison.
Scenarios	It is recommended that a number of scenarios be studied that consider issues such as the levels of voltage support capability offered by different types of VRE power plants and critical load and power transfer levels for voltage stability in the region. The evaluation should consider a high VRE production case in which minimum conventional synchronous generation is online. (Voltage stability problems normally occur in heavily stressed systems.)
Model requirements	**Philippine transmission grid:** Dynamic alternating current (AC) model with the existing topology and typical operating scheme (open breakers and the like), including validated dynamic models for all conventional generators for the area concerned. Depending on the detail desired, the subtransmission system may need to be modeled as well, particularly in relation to transformer tap controls, any reactive power compensation in the system, and voltage-dependent loads. However, to investigate the general impact, it may be adequate to assume that transformer taps are fixed and that WPPs operate at unity power factor, that is, that they do not participate in voltage control. (This was done in the All Island TSO Facilitation of Renewables Study , for example. See Bömer and others 2010.) **Wind and solar PV power generation:** Aggregated dynamic model of power plant including its low voltage ride-through and voltage support capabilities. Include P&Q output based on fixed wind speed (or solar irradiation) for high power outputs. **Loads:** Static load or voltage-dependent loads such as inductive loads. **Other generation:** Dynamic models including excitation systems, power system stabilizers, and external reactive power devices. **Protection relays:** Generator and system protection relays that cause generators to cut off when low voltage is detected should be modeled.
Data requirements	**Demand:** Projected future peak and off-peak demand for all nodes in network model (maximum and minimum demand in MW). **Generation:** Projected future installed generation capacity and corresponding availability during peak and off-peak periods (in MW). An estimate of the voltage support capability of future WPPs and solar PV plants. These capabilities should be benchmarked against an existing WPP with "typical values" rather than assuming the worst case behavior, given that performance standards vary between WPP sites.

(continued)

How to interpret results and the expected output	If the simulation results in a voltage collapse or voltage limit violation, maximum VRE penetration limits may need to be imposed unless further measures are taken (such as adding dynamic volt-amps reactive [DVar] systems). The most common solution for preventing voltage collapse is to require low voltage ride-through capabilities from the VRE power plants in the grid code. Low voltage ride-through capabilities can be supplied by modern wind turbines and solar PV inverters, but can also be supplied by external reactive power devices like DVars. For voltage regulation, dynamic reactive power support capabilities can also be demanded from the VRE plants or provided by external reactive power devices like static reactive compensators (SVCs). Because performance requirements are likely to vary among locations, the requirement may be determined on a location-by-location basis, as is done in the Australia National Electricity Market (in which each plant must meet its own unique technical standard). Alternatively, a standardized approach could be used as in Europe, where the minimum performance requirement from a power plant is stipulated in the grid code. Voltage issues are expected to be prevalent in areas that are weakly interconnected. Because no FRT requirement is applied at present, a hard limit on VRE that can be installed in certain regions or connection points is likely to exist. However, rather than limiting the amount of VRE that can be integrated based on the current grid code (with no FRT requirement), it would be better to set a reactive power support capability requirement in the grid code to eliminate these types of problems.

For grid planning studies to generate robust solutions that are widely supported by both industry and government, relevant stakeholders must be involved in the project preparation phase. Stakeholder input will be valuable during discussion of the variety of assumptions that can affect the diversity of future scenarios. Particularly with regard to the anticipated geographic areas of development for wind and solar power, consultation with industry is strongly recommended to ensure wide acceptance of the study findings. Also, support from the government and regulatory authority will aid with gaining credibility and maybe even policy-backed support to drive the development of key transmission augmentations.

Stakeholders required	National Grid Corporation of the Philippines (NGCP), National Renewable Energy Board (NREB), renewable energy advocates, generation project developers, Department of Energy (DOE), Energy Regulatory Commission (ERC)
Key reference studies	**Power flow and stability studies:** All Island Grid Study WS3, Department of Communications, Marine and Natural Resources in the Republic of Ireland and the Department of Enterprise, Trade and Investment in Northern Ireland (TNEI), 2007–12. EWI, E.ON Grid, EWI, RWE Transport Grid Electricity, VE Transmission. 2005. "Energy Management Planning for Integration of Wind Energy into the Grid in Germany, Onshore and Offshore by 2020," Deutsche Energie-Agentur GmbH (dena), Cologne. Southwest Power Pool Wind Integration Study, WITF Final Report, SPP (Charles River Associates), 2010–01. Integration of Renewable Resources: Transmission and Operating Issues and Recommendations for Integrating Renewable Resources on the California ISO-controlled Grid, California ISO, 2007–11. Growing Wind: Final Report of the NYISO 2010 Wind Generation Study, NYISO, 2010–09. CREZ Reactive Power Compensation Study, ERCOT (ABB), 2010–12. **Market-coupled studies:** TradeWind, EC (EWEA, Risoe, et al.), 2009–05. ENTSO-E and European Commission. 2010. "European Wind Integration Study (EWIS): Towards A Successful Integration of Large Scale Wind Power into European Electricity Grids," Brussels. **Large grid augmentations and EHV overlay studies:** EnerNex Corporation. 2011. "Eastern Wind Integration and Transmission Study," National Renewable Energy Laboratory, Golden Colorado. SSP EHV Overlay Project, SPP (InfraSource, PowerWorld), 2007-06. Strategic Midwest Area Renewable Transmission (SMARTransmission) Study, Quanta Technology, 2010. **General:** Transmission Planning for Wind Energy: Status and Prospects, C. Smith, et al., 2010–10. The Cost of Transmission for Wind Energy: A Review of Transmission Planning Studies, A. Mills, et al., Berkley National Laboratory, 2009–02.

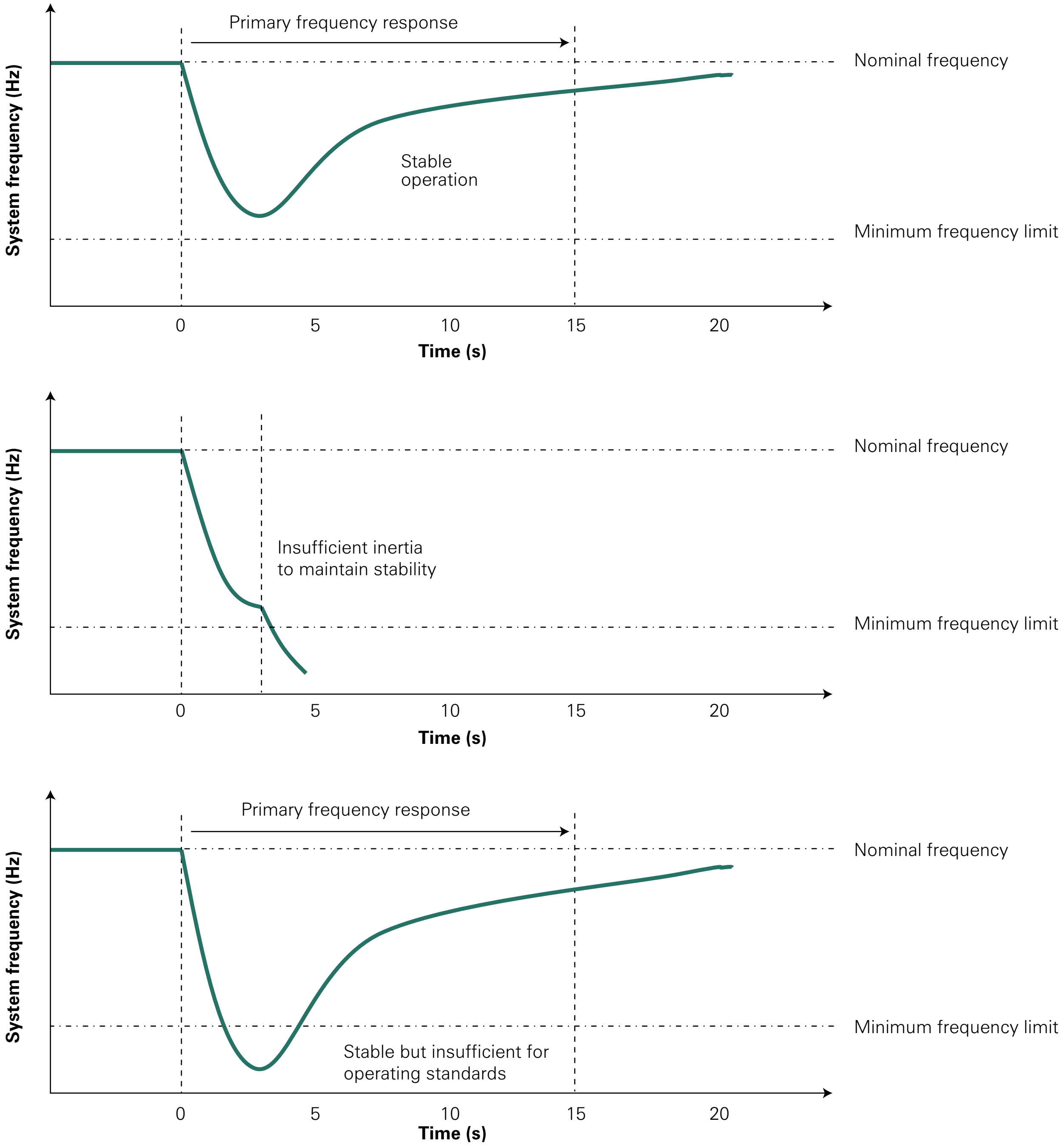
3.3. Inertia and Frequency Response of Island Systems

The inertia and frequency response study investigates whether the power system has adequate inertia to prevent frequency excursions that cannot be controlled by primary reserve.

As identified by the IEA Wind Task 25 report, frequency control and inertial response are not considered crucial problems for wind power integration at the present levels of penetration seen around the world. However, it can be a challenge for small (particularly island) systems, as demonstrated by the Irish "All Island TSO Facilitation of Renewables" study (Bömer and others 2010). Because the Philippine power system is a series of island systems interconnected by weak links, a hard technical limit to VRE penetration may be required. This study may reveal the maximum limit of "inertia-less" generation that can be integrated in relation to total power production. The Irish "All Island TSO Facilitation of Renewables" study commissioned by Eirgrid, resulted in a 60–80 percent "inertia-less" penetration limit.

Objective	To determine whether a limit exists for the penetration of "inertia-less" generation in each of the regional grid systems (Luzon, Visayas, and Mindanao).
Methodology	The system frequency response can be studied by performing dynamic simulations of the sudden loss of generation and observing the resulting frequency nadir. If the frequency nadir falls below the limit for under-frequency load shedding in the first few seconds, it can be concluded that there is insufficient inertia in the system to control the frequency excursion within the stipulated limits (see figure 3.5). To determine whether there is a maximum limit for the penetration of "inertia-less" generation, a series of simulations need to be performed, starting with 100 percent penetration, then decreasing penetration levels gradually until the observed frequency nadir ceases to fall below the minimum allowable frequency. To assess the adequacy of the existing primary reserves, determine whether the system frequency can be brought back up to within the stipulated range by a certain time.
Scenarios	**Luzon:** Maximum import via high voltage, direct current (HVDC) link and high VRE power generation supplying low demand. **Visayas:** Maximum import via HVDC link and high VRE power generation supplying low demand. **Mindanao:** High VRE power generation supplying low demand. **Other:** Other regions with particularly low cross-island interconnection capacity (high voltage alternating current) may also be studied assuming island mode operation.
Model requirements	**Philippine transmission grid:** Acquire full dynamic system models of the region studied. Generator governor models should be included as should be an appropriate dynamic model for the HVDC converters. **Wind power generation:** Determine aggregated P&Q output of WPP based on fixed wind speed. Wind turbine modelling requirements depend on the assumptions made about the capabilities of the turbines. Option A: No inertia or primary reserve contribution—model new wind generation as doubly fed induction generator (DFIG) turbines with appropriate voltage support capability. Option B: Virtual inertia or primary reserve contribution—appropriate modeling of the offered capability is required. Option C: Inertia contribution caused by direct-coupled wind turbine model—model inertia contribution of existing wind generation as appropriate. **Solar PV models:** Aggregated P&Q output of solar PV power plant based on fixed irradiance. Assume no inertia contribution.
Data requirements	**Demand:** Projected future off-peak demand for all nodes in the network model (maximum and minimum demand in MW). **Generation:** Projected future installed generation capacity and corresponding availability during off-peak periods (in MW).
How to interpret results and the expected output	If the simulation results in uncontrollable frequency excursion and load shedding, maximum VRE penetration limits may need to be applied unless further measures are taken. This limit, however, is expected to be at quite a high penetration rate. For instance, for the Irish grid it was 60–80 percent. Therefore, a limit might be found, but it is unlikely to be a short-term issue. Therefore, this study could be delayed—keeping in mind, however, that specific island systems could end up with higher penetration rates than others. At present, the solution to such a problem would be to impose a maximum "inertia-less" generation penetration limit, to ensure that enough synchronous generators are online at all times. However, new developments in wind turbine technologies have been made that offer "virtual inertia" capabilities. Therefore, when higher future penetration rates are expected, virtual inertia capability may be incorporated as a grid code requirement.

Figure 3.5. Stable and Unstable System Frequency Response Following the Sudden Loss of Generation



Source: Authors.

To obtain accurate models of the regional networks for performing frequency stability studies, it is important that the system operator of each grid be involved in the study.

Stakeholders required	NGCP, generator owners, wind and solar PV project developers, NREB, DOE, ERC
Key reference studies	Bömer, J., K. Burges, C. Nabe, and M. Pöller. 2010. "All Island TSO Facilitation of Renewables Studies: Final Report for Work Package 3," EirGrid, Dublin. Transpower New Zealand. 2007. "Wind Generation Investigation Project 5: Effect of Wind Generation Capability on Management of Frequency Excursions." Transpower New Zealand, Wellington, New Zealand. Fast Simulation of Wind Generation for Frequency Stability Analysis in Island Power Systems, James Conroy, 2010-10. Dynamic Simulation Studies of the Frequency Response of the Three US Interconnection with Increased Wind Generation, Berkley National Laboratory, 2010-12. Roam Consulting. 2010. "Assessment of FCS and Technical Rules," Independent Market Operator,Perth, Australia.

3.4. Fault Level Adequacy for HVDC Link Operation (and Protection Relays)

The fault level adequacy study investigates whether the addition of new generation changes the general system fault level in such a way that proper HVDC operation is inhibited. This could potentially be an issue if the amount of VRE in Luzon or Visayas causes the general fault level to fall—the two regions are interconnected with an HVDC link, and this link has been critical for supplying enough power to meet demand in Luzon.

The maximum amount of VRE that can be integrated without causing the HVDC and protection equipment to malfunction could be calculated. However, the resources required to perform a full short-circuit study are extensive. Therefore, it is recommended that a general impact study be performed first. If the general study indicates that a severe impact is likely, then a detailed study should be performed to determine the absolute maximum amount of penetration.

The fault current contribution of VRE power plants is highly dependent on their FRT capability. Therefore, the grid code must establish requirements for new and existing VRE generation for fault ride-through, and must be accurately represented in the study.

Objective	A) Indicative study To assess whether the impact of new VRE installations on the system fault level is likely to be an issue for correct HVDC link operation. B) Maximum VRE penetration study To determine the maximum amount of VRE that can be integrated into the power system without causing the short-circuit ratio of the HVDC link to fall below minimum.
Methodology	A) Indicative study Steady-state analysis can be performed for different VRE penetration scenarios to assess the general impact on the short-circuit level at the terminals of the HVDC link. B) Maximum VRE penetration study Electromagnetic time domain transient simulations can be performed for balanced and unbalanced short-circuit faults at particular points in the network, such as the connection point of the WPP or at the terminals of the HVDC device.

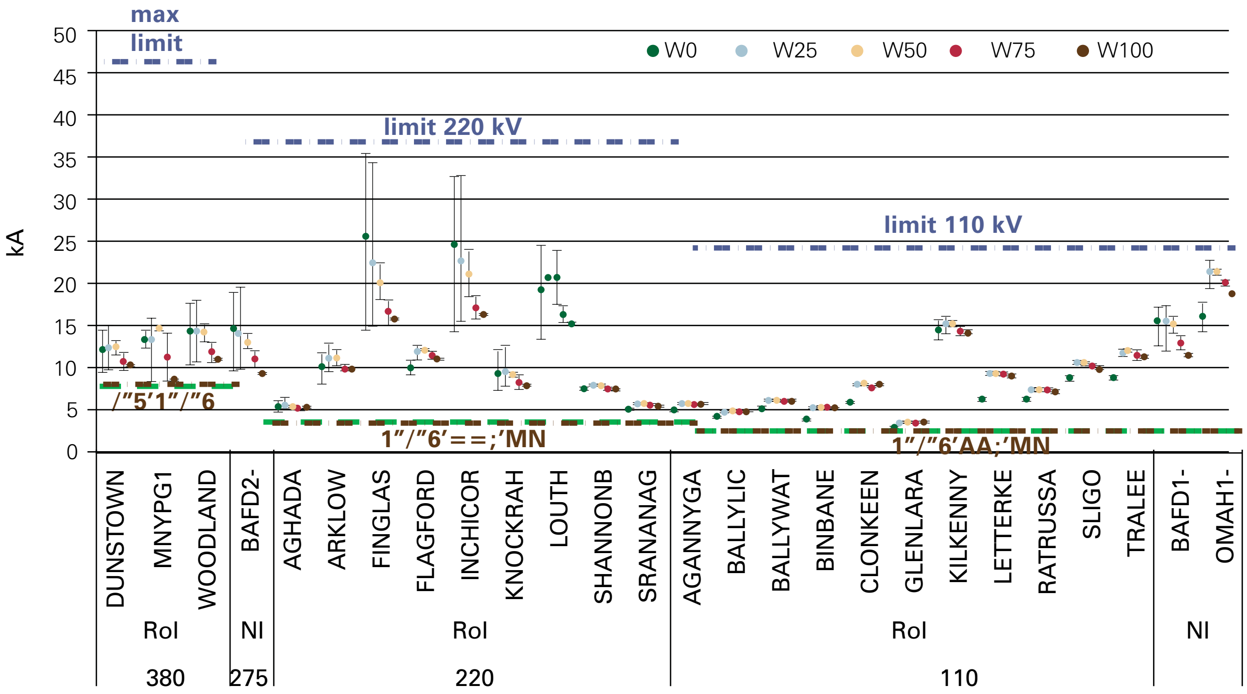
(continued)

Scenarios	High wind and solar PV development. Series of interconnector capacity levels. Short-circuit current is normally provided by conventional synchronous generators. Therefore, the worst case scenario is a low load situation in which most conventional generation is displaced by wind generation. HVDC-LUZON: High wind power generation supplying low demand. HVDC-VISAYAS: High wind power generation supplying low demand.
Model requirements	A) Indicative study **Luzon and Visayas transmission grid:** AC power flow model with the existing topology and typical operating scheme (open breakers and the like). **Wind power generation:** Aggregated P&Q output of WPPs based on fixed wind speed for high and low wind power outputs. **Solar PV power generation:** Aggregated P&Q output of solar PV power plant based on fixed solar irradiation for high and low solar PV power output. **Other generation:** P&Q model with full availability corresponding to the time point analyzed, including external reactive power devices. B) Maximum VRE penetration study Electromagnetic model of WPP and connection point with equivalent grid representation.
Data requirements	**Demand:** Projected future off-peak demand for all nodes in network model (maximum and minimum demand in MW). **Generation:** Projected future installed generation capacity and corresponding availability during off-peak periods (in MW).
How to interpret results and the expected output	If the simulation results show that the short-circuit ratio at HVDC terminals will fall below minimum operating requirements, maximum VRE penetration limits may need to be imposed unless further measures are taken. This outcome is highly dependent on the FRT capability and short circuit current contribution characteristics of the VRE. This situation is known in general to lower the fault level (Bömer and others 2005; Transpower New Zealand 2008), but in some cases it may even increase the fault level (figure 3.6). Therefore, careful observation is required using accurate models of the type of VRE that will be installed. The most common solution for preventing fault level reduction from affecting HVDC operation is to implement an operation limitation such as a minimum-must-run generation unit. The protection equipment might need to be redesigned so that it functions properly with the new fault level.

The system operator of each region, as well as the operators of WPPs and the HVDC link, must be involved in the study to ensure that accurate models of the regional grids are obtained for performing fault level studies.

Stakeholders required	NGCP and its system operators, WPP owner, HVDC link operator
Key reference studies	Bömer, J., K. Burges, C. Nabe, and M. Pöller. 2010. "All Island TSO Facilitation of Renewables Studies: Final Report for Work Package 3," EirGrid, Dublin. Transpower New Zealand. 2008. "Wind Generation Investigation Project 9: Effect of Wind Generationon Reactive Power Contribution and Dynamic Voltage Responses." Transpower New Zealand, Wellington, New Zealand. Wind Power Plant Short Circuit Current Contribution for Different Fault and Wind Turbine Topologies, V. Gevorgian, et al., NREL, 2010–10.

Figure 3.6. Example of Different Wind Power Penetration Levels (0, 25%, 50%, 75% 100%) on the Three-Phase Faults at Selected Bus Bars in Ireland (Around Each Average Value the Minimum and Maximum Short Circuit Currents Over 63 Load Cases are Indicated by the Error Bar)



Source: [15], page 53.

3.5. Reserve Adequacy for Expected Forecast Errors[10]

The types of reserves that exist, and how they are determined, often differ between power systems, making it challenging to apply a general methodology. However, some papers (Holttinen, Milligan, and others 2012; Holttinen, Meiborn, and others 2009; Soder and Holttinen 2008) attempt to bridge the gap, and methodologies presented in this section are drawn from their findings. Many studies also attempt to calculate the percentage increase in reserves required to integrate a certain amount of VRE, as well as the associated costs.

For the reserve adequacy study, at least two reserve types should be studied. (According to the definition of reserves in the Philippines, more types may need to be assessed.) The two minimum types are

- secondary reserves for regulation (1–5 minutes), and
- tertiary reserves for balancing (5–30 minutes).

These reserves are often determined and acquired through ancillary service contracts or the ancillary services market; however, systems with short gate closure times like the Australian NEM (5 minutes) handle the task of ensuring adequate reserves in the dispatch market, and only need to secure reserves for frequency regulation.

In the Philippines, both types of reserves are covered by the secondary response of load following and frequency regulating reserves. (Refer to figure 2.6 and table A1 in appendix A for definitions.) The requirement for load following and frequency regulating reserves is set equal to the average load forecast variance (4 percent in Luzon)

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[10] Impacts from "expected forecast errors" are part of normal operation, that is, non-event cases. Impacts from unexpected events (contingency and event reserve) are assessed in the study in the next section.

(Philippine Wholesale Electricity Spot Market 2004). However, because the addition of VRE will compound the level of uncertainty, the reserve requirement should also take into account the variance of the VRE output.

Two methods are commonly used to evaluate the reserve requirement—the statistical method and the convolution method.

The statistical method involves the evaluation of load and generation output variability and forecast errors. The variances of these components are summed to find the variance of the net load.[11] The additional reserves required to cover the integration of VRE can then be calculated as the difference between the standard deviations of the net load and the load, multiplied by some factor to achieve the required confidence level.

The convolution method involves evaluation of probability density distributions for VRE and load variability and associated uncertainties. These are then superimposed by convolution to find the magnitude and frequency of all potential imbalances.

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[11] Net load is demand minus VRE power output.

Objective	A) Maximum VRE penetration study To determine the maximum amount of VRE that could be integrated into the power system without needing to increase the load following and frequency regulating reserves. B) Assessment of reserve requirements To assess the load following and frequency regulating reserves required to integrate high levels of RES-E advocated by government policies.
Methodology	The statistical method for evaluating the reserve requirements is recommended because of its simplicity. Historical demand profiles scaled to future demand levels and a reproduction of VRE output profiles based on historical weather data (for example, wind speed, solar radiation) are required. Reproduction of future demand and VRE power outputs on 1-minute or 5-minute basis is recommended. Calculate the net load by subtracting the VRE power output from time-correlated demand, and find the statistical variance of the net load. According to the methodology currently applied in the Philippines, the average variance is the required amount of reserve. However, to make sure that the required reserves allow the system operator to meet reliability standards, a more detailed method may need to be used. Forecast values and resulting forecast errors, as well as forced outages, can also be included in this analysis to capture all types of uncertainty of load, wind, and other production. Additionally, the associated costs of each scenario can be calculated for comparison.
Scenarios	The reserve requirements for at least two scenarios should be evaluated for comparison for each island. **Base Case:** without VRE development. **VRE Integration Case:** with VRE. If desired, a number of scenarios could be developed, with varying degrees of VRE integration. **Interconnector Sensitivity (Optional):** to compare the regulation reserve requirements for different interconnector use strategies. For example, base load could be covered by interconnector imports to free up generation that can provide reserves.
Model requirements	Wind and solar PV power plant output models that can estimate the active power output based on wind speed and solar radiation data.
Data requirements	**Demand:** Normal historical demand for one year on a 1-minute or 5-minute basis, scaled to future demand level. **Wind and solar PV generation:** Generation output on a 1-minute or 5-minute basis, calculated from historical wind speed and solar radiation time series data synchronized with demand at the expected installation locations.
How to interpret results and the expected output	If the reserve requirement WITH VRE exceeds the requirement for load only, maximum VRE penetration limits may need to be imposed unless further measures are taken. Energy penetration rates of about 10 percent are expected to have virtually no impact on the regulating reserves. Therefore, in Luzon and Visayas, where average energy penetration will be less than 10 percent (resulting in an instantaneous maximum penetration level of 35 percent), the impact on reserve requirements will be marginal.

To model the outputs of wind and solar PV power plants accurately, a good understanding of the planned locations of the power plants is required, along with detailed wind speed and irradiance. In addition to the generation developers, organizations that have extensive weather data, such as the bureau of meteorology, should be consulted, as should be renewable energy advocates.

Stakeholders required	NGCP, NREB, renewable energy advocates, renewable generation project developers, wind speed measurement providers, solar irradiation measurement providers
Key reference studies	**General:** Holttinen, H., M. Milligan, E. Ela, N. Menemenlis, B. Rawn, R. Bessa, D. Flynn, E. Gomez-Lazaro, J. Dobschinski, and N. Detlefsen. 2012. "Methodologies to Determine Operating Reserves due to Increased Wind Power." IEEE Transactions on Sustainable Energy, no. Special Issue: Wind Energy. Holttinen, H., P. Meibom, A. Orths, F. van Hulle, B. Lange, M. O. O'Malley, J. Pierik, B. Ummels, J. O. Tande, A. Estanqueiro, M. Matos, E. Gomez, L. Söder, G. Strbac, A. Shakoor, J. Ricardo, C. J. Smith, M. Milligan, and E. Ela. 2009. "Design and Operation of Power Systems with Large Amounts of Wind Power." Final report, IEA WIND Task 25, Phase one 2006-2008. VTT Tiedotteita, Helsinki. Milligan, M., P. Donohoo, D. Lew, E. Ela, B. Kirby, H. Holttinen, E. Lannoye, D. Flynn, M. O'Malley, N. Miller, P. Børre Eriksen, A. Gøttig, B. Rawn, M. Gibescu, E. Gómez Lázaro, A. Robitaille and I. Kamwa. 2010. "Operating Reserves and Wind Power Integration: An International Comparison." National Renewable Energy Laboratory (NREL), Golden, Colorado.
	USA: EnerNex Corporation. 2011. "Eastern Wind Integration and Transmission Study," National Renewable Energy Laboratory, Golden Colorado. GE Energy. 2010. "Western Wind and Solar Integration Study," National Renewable Energy Laboratory (NREL), Golden, Colorado. GE Energy. 2008. "Analysis of Wind Generation Impact on ERCOT Ancillary Services Requirements." GE Energy, New York.
	Quebec: Dernbach, M., D. Bagusche, and S. Schrader. 2010. "Frequency Control in Quebec with DFIG Wind Turbines," in 9th International Workshop on Large-Scale Integration of Windpower into Power Systems/Transmission Networks for Offshore Wind Power Plants, Quebec City. Kamwa, I., A. Heniche, and M. de Montigny. 2009. "Assessment of AGC and Load-Following Definitions for Wind Integration Studies in Quebec." energynautics, Langen, Germany. de Montigny, M., A. Heniche, I. Kamwa, R. Sauriol, R. Mailhot, and D. Lefebvre. 2010. "A New Simulation Approach for the Assessment of Wind Integration Impacts on System Operations," 9th International Workshop on Large Scale Integration of Wind Power and on Transmission Networks for Offshore Wind Farms, pp. 460–67, Quebec City, October 16–17.
	Hawaii: Miller, N., D. Manz, H. Johal, S. Achilles, L. Roos, and J. P. Griffin. 2010. "Integrating High Levels of Wind in Island Systems: Lessons from Hawaii," in International Conference on Sustainable Energy Technologies, pp. 1–8, December.
	Ireland: Sustainable Energy Ireland. 2004. "Operating Reserve Requirements as Wind Power Penetration Increases in the Irish Electricity System." Sustainable Energy Ireland, Dublin.
	Western Australia: Roam Consulting. 2010. "Assessment of FCS and Technical Rules," Independent Market Operator, Perth, Australia
	New Zealand: Transpower New Zealand. 2007. "Wind Generation Investigation Project 5: Effect of Wind Generation Capability on Management of Frequency Excursions." Transpower New Zealand, Wellington, New Zealand.

3.6. Reserve Adequacy for Extreme Ramps

This reserve adequacy study investigates whether there are enough primary and tertiary event reserves (corresponding to contingency spinning and backup reserves in the Philippines) for supply to meet the expected load when VRE is added to the system. Event reserve refers to spinning reserves for contingency response and backup reserves replacing other reserves, as well as reserves to deal with slow contingency events (such as weather-induced ramps) (refer to figure 2.6 and table A1 in appendix A for definitions). These reserves are often determined and acquired through the ancillary services market, or through direct instruction (must-offer); however, markets with short dispatch times such as the Australian NEM (5 minute) handle tertiary reserves in the dispatch market, and are not as concerned.

In the Philippines, contingency reserve is defined as reserve equivalent to the largest loss of supply that could be caused by disconnection of the largest online generation unit or by the outage of a circuit.

Presently, the largest unit in Luzon is a gas unit of about 1,200 MW, while the largest expected VRE plant is a WPP of less than 150 MW. Thus, integration of the WPP will not require an increase in primary reserve. Even in the worst case—for example, none of the WPPs are equipped with FRT capability and trip off in the event of a voltage dip—the largest aggregation of VRE in one region (northern Luzon) is expected to be less than 350 MW. Therefore, it is unlikely that the reserve requirement will need to be changed.

According to the presentation by DoE, however, for Visayas and Mindanao, the largest units are about 100 MW, whereas the largest proposed WPP is 122 MW (in Visayas). Therefore, the primary reserve requirement for these regions will possibly need to be changed.

More challenging is the tertiary reserve. According to Holttinen, Milligan, and others (2012), compensating for large but slow events, corresponding to forecast errors for 10 minutes to some hours ahead, is the most challenging based on international studies. Furthermore, extreme ramping caused by weather or market events may be caused specifically by the introduction of VRE.

Currently, the only tertiary reserve in the Philippines is for replacement of the contingency reserve, called the "backup reserve." There are no reserves that can be deployed between regulating reserves (25 seconds to 30 minutes) and market dispatch (1 hour).

For a slow contingency event that becomes apparent in advance, such as the approach of a storm front, a loss of power in less than 1 hour[12] could potentially be a problem because neither regulation reserve nor primary contingency reserve is designed to cover for this additional loss. Rather than adding this potential loss to costly spinning reserve, whether regulating reserves would be adequate to cover this kind of event should be examined, and creation of a new reserve category might even be considered.

To find the maximum VRE level that does not cause such a situation, historical weather events should be studied and the maximum ramp rate should be compared with existing reserve requirements.

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[12] Dispatch is one hour, and regulating reserve has the capability to come online in 30 minutes.

Objective	To determine the maximum amount of VRE that could be integrated without the need to increase regulating reserves.
Methodology	Review historical weather data and determine probable "worst case" scenario that results in maximum ramping of wind power output in northern Luzon, and solar PV power wherever large installations are planned. Estimate the maximum wind (or solar) generation change event in the high VRE penetration scenario based on the weather data. For dispatch and short-term capacity reserves, perform market dispatch simulations.
Scenarios	The reserve requirements for at least two scenarios should be evaluated for comparison for each island. **Base Case:** without VRE development. **VRE Integration Case:** with VRE. If desired, a number of scenarios could be developed, with varying degrees of VRE integration. (Start with maximum and reduce until the limit is found.) On- and off-peak demand scenarios with high VRE penetration, in which the minimum number of units providing reserves are online.
Model requirements	Philippine transmission grid: Dispatch model **Wind and solar PV power generation:** WPP and solar PV power plant output model that can estimate the active power output based on wind speed and solar radiation data. Models may include advanced capabilities such as active power reduction and delta control. **Capability of conventional units:** Ramp rates, start-up, shut down, fuel costs, and so forth.
Data requirements	**Data based on a real event:** 5-minute wind power and solar PV output corresponding to wind speed and solar irradiation during the actual extreme weather event identified. Corresponding load data and generation availability at the time of the event. **Demand:** Historical demand for a period that includes extreme weather events on a 1-minute or 5-minute basis, scaled to future demand level. **Wind and solar PV generation:** Generation output on a 1-minute or 5-minute basis, calculated from historical wind speed and solar radiation time series data synchronized with demand at the expected installation locations.
How to interpret results and the expected output	If the reserve requirement with VRE exceeds the requirement for load only, maximum VRE penetration limits may need to be imposed unless further measures are taken. It is expected that a slow ramp event in Luzon will have an impact on regulating reserve. However, rather than limiting VRE, it may be advisable to revise the regulating reserve requirement definition or create a new type of ancillary service. The benefit of allocating interconnector capacity for transfer of reserves may also be explored.

To model the weather impact on power plant outputs accurately, a good understanding of the planned location of WPPs and solar PV plants is required , along with the characteristics of the generation technology employed, and the type of weather events experienced in that region. In addition to the generation project developers, organizations that have extensive weather data, such as the bureau of meteorology, should be consulted. Renewable energy advocates such as the Clean Energy Council should also be consulted.

Furthermore, to represent the services offered by generators and their operation capabilities accurately, it is important to involve both renewable and conventional power generators. For example, for some studies in the United States, industry representatives have complained that the operational capability of conventional generators has been overestimated and costs underestimated, so that the results do not adequately reflect the true effort required to integrate VRE generation. By the same token, the frequency regulation capabilities that can be offered by WPPs and solar PV inverters must also be taken into consideration.

Stakeholders required	NGCP, NREB, renewable energy advocates, renewable generation project developers, conventional generator owners, weather bureau, wind speed measurement providers, solar irradiation measurement providers, VRE output forecasters, DOE, ERC
Key reference studies	GE Energy. 2008. "Analysis of Wind Generation Impact on ERCOTAncillary Services Requirements." GE Energy, New York. Piwko, R., X. Bai, K. Clark, G. Jordan, N. Miller, and J. Zimberlin. 2005. "The Effects of Integrating Wind Power on Transmission System Planning, Reliability, and Operations," GE Energy, New York.

3.7. Treatment of Wind Power in Long-Term Reliability Assessment

When VRE power begins to replace retiring conventional generation instead of being added to existing capacity, VRE's capacity contribution to reliability must be assessed so that long-term reliability standards are not breached. Reliability metrics are the best tool for accurately calculating the capacity credit (dependable capacity) of wind and solar PV power.

For such a study, extensive load, wind power, and solar power output data on an hourly basis are required. In locations in which WPPs and solar PV plants still do not exist, the outputs will have to be estimated based on wind speed and solar irradiance data. Therefore, ***such data must be collected early on***, and providers of such data must be made part of the study.

It is also important to consider the impact of hydro generation, particularly in systems with significant shares of hydro power, as in the Philippines. Generation adequacy must be assessed for both reliability and power, and must take into consideration dry periods, not limiting the study to high and peak demand periods.

Stakeholders required	NGCP, NREB, wind speed measurement providers, solar irradiation measurement providers, generator owners, DOE, ERC
Key reference studies	Holttinen, H., P. Meibom, A. Orths, F. van Hulle, B. Lange, M. O. O'Malley, J. Pierik, B. Ummels, J. O. Tande, A. Estanqueiro, M. Matos, E. Gomez, L. Söder, G. Strbac, A. Shakoor, J. Ricardo, C. J. Smith, M. Milligan, and E. Ela. 2009. "Design and Operation of Power Systems with Large Amounts of Wind Power." Final report, IEA WIND Task 25, Phase one 2006-2008. VTT Tiedotteita, Helsinki. A Review of Different Methodologies Used for Calculation of Wind Power Capacity Credit, L. Söder, et al., KTH, 2008. Milligan, M., and K. Porter. 2008. "Determining the Capacity Value of Wind: An Updated Survey of Methods and Implementation." NREL, Golden, Colorado. Valuing the Capacity of Intermittent Generation in the South-west Interconnected System of Western Australia, REWG WP2, IMO (MMA) 2010-01. Supplementary Analysis of Capacity Valuation, REWG WP2, IMO (MMA) 2010–04. Analysis of Procedures for Assessing the Capacity Value of Intermittent Generation in the Wholesale Electricity Market, REWG WP2, IMO (MMA) 2010-08.

3.8. Electromechanical Impact

When VRE power begins to displace synchronous generation in significant proportions (above 80 percent) to supply load (as in Spain, Portugal, and Ireland today), it is possible that the electromechanical characteristics of the system will change. This may cause the system oscillatory mode to change, rendering inadequate the system damping and power system stabilizer settings. To investigate this possibility, modal analysis by eigenvalue calculation of small-signal stability with and without VRE would need to be evaluated and compared. This analysis was done in the studies by Transpower, ENTSO-E and the European Commission (2010), and the "All Island Facilitation of Renewables", but all of them reported that no significant impact was observed for the particular renewable scenarios studied.

Another potential concern occurs if the VRE power plants are expected to be connected by series-compensated lines or HVDC devices because of their remote location (that is, offshore). Subsynchronous interaction with certain types of wind turbine generators and converter electronics has been discovered to potentially interact with series compensation and HVDC electronics resulting in significant damage, as demonstrated by the event in ERCOT. Therefore if such situations are foreseen, investigation may be warranted.

VRE impact on transient stability has been studied in DENA and some others, but no significant impact has been observed. VRE generation is normally connected via inverters, which do not interfere with the electromechanics of the system directly, so no impact is expected.

Stakeholders required	Market operator, system operators, HDVC owners
Key reference studies	Small-signal study Effect of Wind Generation on Small Signal Stability, WGIP Investigation 8, Transpower NZ, 2008–03. Bömer, J., K. Burges, C. Nabe, and M. Pöller. 2010. "All Island TSO Facilitation of Renewables Studies: Final Report for Work Package 3," EirGrid, Dublin. ENTSO-E and European Commission. 2010. "European Wind Integration Study (EWIS): Towards A Successful Integration of Large Scale Wind Power into European Electricity Grids," Brussels. Subsynchronous Interaction Study CREZ Reactive Power Compensation Study, ERCOT (ABB), 2010–12. The Impact of Wind Farms on Sub Synchronous Resonance in Power Systems, Elforsk (Gothia Power), 2011-04. Sub Synchronous Interactions with Wind Farms Connected Near Series Compensated AC Lines, A. K. Jindal, et al., 2010–10.

4. CONCLUSIONS

The aim of this report is to show what kind of system-wide studies should be carried out in the Philippines to assess the impacts of variable renewable energy (VRE) and to determine whether limits need to be imposed on the level of integration. The report is based on a review of international experience in studying and dealing with VRE integration.

The types of issues that are of particular concern to VRE integration, especially for small island systems like those of the Philippines, were found to be the following:

- The need to build up transmission capacity to evacuate VRE power, which is often in remote areas of the network, and the importance of robust grid design to deal with the potential rapid expansion of VRE generation capacity. Robust designs can be developed based on a variety of scenario studies as part of long-term planning, and including an assessment of extreme weather impacts is vital.
- The need to implement voltage support measures such as fault ride-through requirements on VRE power plants. Some geographical areas depend on the voltage profile of the grid and the support capability of other synchronous generation units. The most common, and therefore the recommended way to reduce negative impacts, is to establish performance requirement standards for VRE power plants. Requirements can be implemented most effectively through the grid code. In addition, voltage support can be obtained from the grid by installing external reactive power devices, or by soliciting additional reactive power services from synchronous generators (for example, requesting them to operate in synchronous condenser mode).
- The need to ensure sufficient inertia in the system to avoid frequency diversions. System-wide general impact studies can be performed, which may lead to a hard operating limit, such as the minimum number of synchronous generators that must be online at any one time. Furthermore, VRE power plants can be asked to contribute to inertia using virtual inertia technology.
- The need for adequate fault levels for correct operation of HVDC devices and protection equipment. System-wide general impact studies can be performed first; if issues are foreseen, detailed studies can be carried out. Detailed short-circuit studies must be carried out as part of the connection studies for individual VRE power plants.
- The ability of the system to balance supply with demand even with the additional uncertainty introduced by VRE power. The amount of reserves required can be estimated using statistical methods based on historical data, or evaluated in detail by simulation of operation processes (pre-dispatch, dispatch, and ancillary service operation). The statistical approach is simpler but less accurate, and large amounts of detailed data are required for either approach. Therefore, the necessary rigor of the study depends on the level of security and reliability required.
- When high penetration is anticipated, it is important to ensure that the installed generation capacity can meet long-term reliability standards. The process for calculating the VRE contribution to reliability is complicated and involves extensive data (more than 10 years). Therefore, it is important to begin collecting data as early as possible, even if high penetration levels are not expected for a long time.

- When high penetration is anticipated, investigations into electromechanical stability may need to be carried out in addition to thermal, voltage, and frequency impact studies. This includes studies of small-signal impact and subsynchronous interactions.
- When particular configurations result in certain wind turbines being connected via series-compensated lines, there is a need to check for SSI.

The current level of VRE in the Philippines is very low compared with many other systems around the world, and international experience has shown that the observed impacts of VRE are minor up to about 20–30 percent penetration. Thus, the Philippines will be able to prepare and carry out the types of studies recommended in this report in parallel with installation of VRE power plants, and can start applying changes to the grid structure, grid code, market structure, and policy framework to be able to cope with higher VRE penetration in the future.

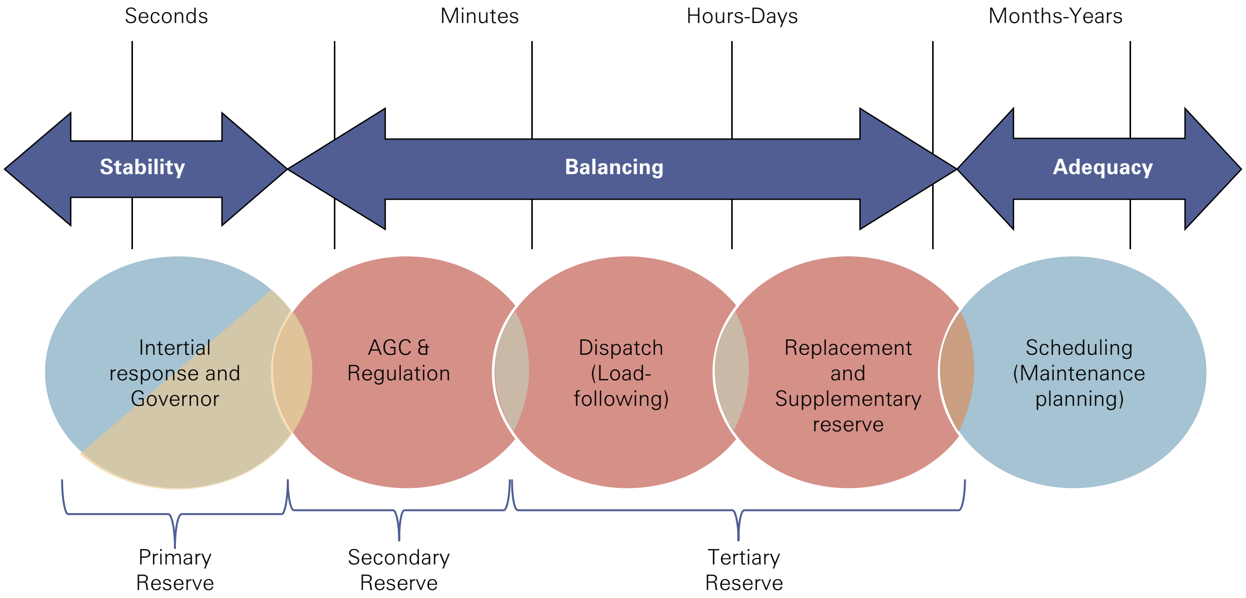
APPENDIXES

Appendix A. Definition of Balancing and Reserves

The goal of power system operation is to balance supply and demand at all times while maintaining reliability and system security standards. Given the few options for storing electricity in a modern power system, the objective is to produce energy at the instant that it is consumed (or shed load when necessary). To facilitate this process in the most efficient manner possible, the system operator optimizes the use of available resources (where electricity markets are in operation, often through markets), under a set of transmission constraints, to meet the electricity consumption forecasted at a certain point ahead of time. The time lag between the forecast schedules and delivery in this process can be broken down into broad categories of a few seconds (governor), 1–5 minutes (automatic generation control and regulation), 5–30 minutes (dispatch or load following), and 30 minutes to some hours (replacement and supplementary reserve). These categories are highlighted in orange in figure A1, and these terms are described in table A1

The definitions of different types of reserves vary depending on the power system. Some of the common terms used are shown in table A1. For the purposes of this report, the terms primary, secondary, and tertiary reserves are used.

Figure A1. Time Scale for Different Operation Mechanisms and Reserves



Source: Authors.

Table A1. Reserve Categories

Name	Use	Common Terms
Contingency reserve	Capacity available for assistance in active power balancing during infrequent events like power plant outages that are more severe than balancing needed during normal conditions and are used to correct instantaneous imbalances	Contingency reserve, disturbance reserve, N–1 reserve
Primary reserve for contingency response	Portion of contingency reserve that is automatically responsive to instantaneous active power imbalance and stabilizes system frequency (primary) and returns frequency to nominal (secondary)	Primary control reserve, frequency responsive reserve, governor droop, secondary control reserve, spinning reserve. automated generation control
Non-event reserve	Capacity available for assistance in active power balance during normal conditions, or those that occur continuously (no faults in system)	Non-event reserve
Secondary reserve for regulation	Capacity available during normal conditions for assistance in active power balance to correct the current imbalance, is faster than economic dispatch optimization, is random, and requires an automatic centralized response	Regulating reserve, regulation, load frequency control, primary/secondary control
Tertiary reserve for balancing	Capacity available during normal conditions for assistance in active power balance to correct a future anticipated imbalance, does not require an automatic centralized response	Load following, following reserve, tertiary reserve, minute reserve, schedule reserve, dispatch reserve, balancing reserve
Event reserve (slow reserve)	Capacity available for assistance in active power balance during infrequent events that are more severe than balancing needed during normal conditions	
Tertiary reserve for slow contingency events	Capacity available for assistance in active power balance during infrequent events that are more severe than balancing needed during normal conditions and is used to correct non-instantaneous imbalances	Ramping reserve, supplemental reserve, balancing reserve
Tertiary reserve for replacing primary and secondary reserves	Portion of contingency reserve that is available for assistance in replacing frequency responsive reserve (primary and secondary) used during a severe instantaneous event so that it is available for a subsequent instantaneous event that occurs in the same direction. Can also be used and dimensioned to include slower ramping events like large forecast errors.	Tertiary control reserve, replacement reserve, supplemental reserve, balancing reserve

Source: Holttinen, Milligan, and others 2012, 2.

Appendix B. Summary of International Experience

A multitude of studies are available in the international domain that assess the impact of variable renewable energy (VRE) integration from a purely technical standpoint, an economic standpoint, and anywhere in between. To ensure the reliability and security of the power system, these studies may propose technical solutions such as either hard limits or soft limits, depending on the operation regime, and may outline possibilities for increasing the limits by enhancing the capability of the system and its components. The decision about the limit to impose and to what degree the existing system should be modified to accommodate VRE will most certainly depend on economic priorities and on the capabilities of the stakeholders involved.

B.1. Study Objectives

The objective of a VRE integration study could be to determine the maximum allowable wind power penetration that requires no major changes to existing infrastructure requirements and operating procedures. Often, however, the main driver for VRE impact studies is an effort to scale up wind and solar PV energies promoted by government policies to meet national or state renewable energy (RE) targets. To achieve RE targets set by governments, systems must adapt; therefore, most studies assess the impact that a certain percentage of VRE integration is likely to have on the system. See table B1.

Based on such studies, measures to accommodate VRE are developed and decisions are made about how best (most efficiently) to implement those decision. The decisions are based on the ability of the system to implement the solutions and allocate the associated costs, as well as the ability of the grid operators and renewable energy developers to adjust to new operational practices.

B.2. Types of Impacts Studied

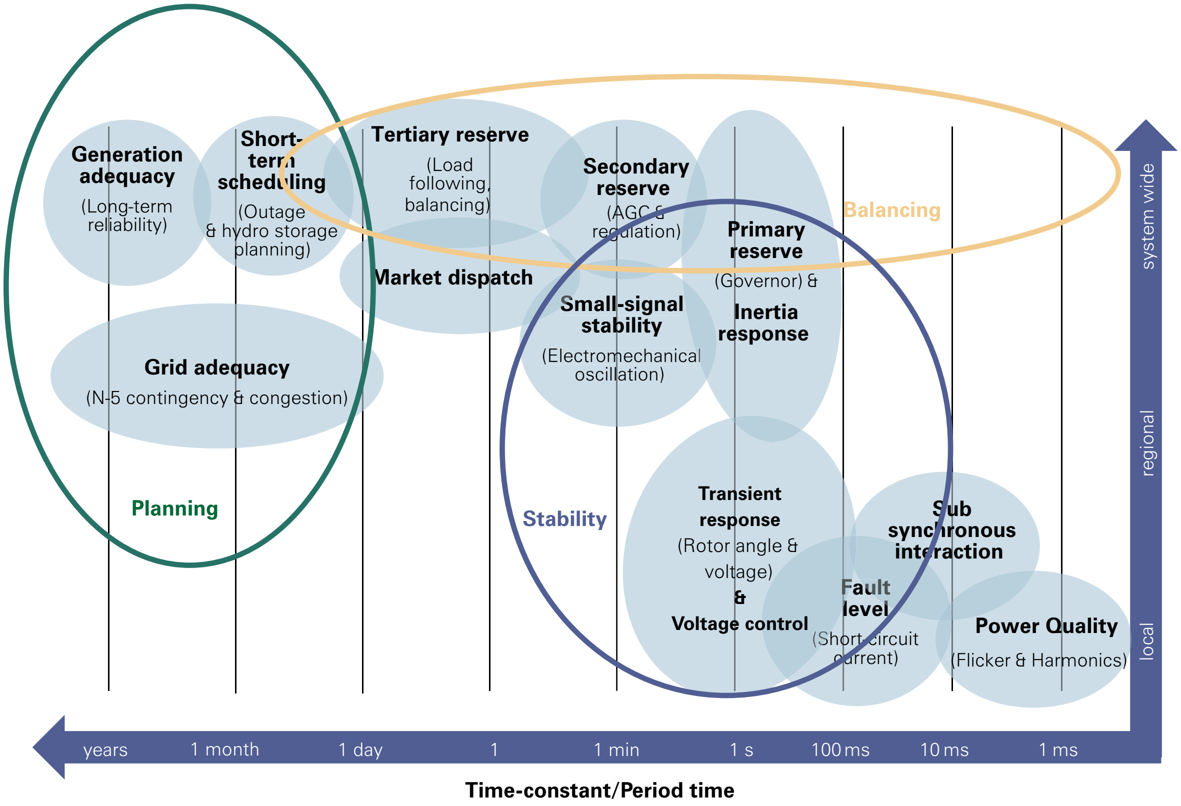
Issues considered in these studies are not particularly unique to VRE; rather, they are the same studies that would be performed for the addition of any new generation. The range of studies can be seen in figure B1.

Table B1. Objectives of Various International VRE Integration Studies

Study Objective	Reference International Study
Maximum generation capacity that can be installed without violating limits	Minnesota Dispersed Renewable Generation Transmission Study (Minnesota Transmission Owners 2008): How to distribute 600 MW of wind and biomass power from 42 sites across five planning zones within the state of Minnesota.
System impacts of a certain percentage of VRE integration (wind power/(minimum load + I/C))	**Europe** European Wind Integration Study, 34 percent penetration (ENTSO-E and European Commission 2010) All Island Grid Study (Ireland), 178 percent penetration DENA Grid Study (Germany), 71 percent penetration (DEWI and others 2005) Denmark, 51 percent penetration (Eriksen and Orths 2008) Red Electrica España, 73 percent penetration (Rodríguez-Bobada and others 2006)
	United States Western Wind Integration Study, 35 percent penetration (energy penetration) (GE Energy 2010) Eastern Wind Integration and Transmission Study, 30 percent penetration (energy penetration) (EnerNex Corporation 2011) ERCOT Ancillary Services Requirements Study (Texas), 23 percent penetration (GE Energy 2008) New York Independent System Operator, 17 percent penetration (Piwko and others 2005) Hawaii, 96 percent penetration (Miller and others 2010)
	Oceania Wind Generation Investigation Project New Zealand, 75 percent penetration Future wind generation in Tasmania study (Australia), 95 percent penetration (Transend 2009)

Source: Authors.

Figure B1. Issues investigated in VRE integration studies



Source: Authors.

However, because of the nature of VRE power, its impact on particular system issues is higher than on others. The characteristics of the power system under consideration also affect the issues that would be more susceptible to impacts from VRE. Thus, certain types of studies are more relevant for VRE integration. The results of these studies are summarized in the following pages.

Balancing[13]

Primary Response and Contingency Reserve

Primary response contingency reserves are generally designed to cover the largest single contingency event in a system, typically caused by the sudden disconnection of a generating unit, a load block, or an interconnector—whichever causes the largest discrepancy between supply and demand as a transient event.

Based on international experience, the conclusion is that the impact of VRE on primary reserve requirements is negligible because the introduction of new VRE power plants generally does not change the size of the single largest contingency,[14] assuming a fault ride-through (FRT) capability is available from the VRE power plants. If the VRE plants are not equipped with FRT capability, a voltage dip may cause a group of plants in one area to trip and become the largest contingency.

Wind power outputs do not change fast enough to constitute a contingency event in normal operation because of the mechanical structure of wind power plants (Holttinen

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[13] Different definitions for balancing mechanisms and reserves are used in different power systems. Refer to appendix A for the definitions of primary, secondary, and tertiary reserves used in this report.

[14] The largest contingency depends on the power system. However, according to the presentation by DoE (2011), for Visayas and Mindanao, the largest units are about 100 MW, whereas the largest proposed WPP is 122 MW (in Visayas). Therefore, it is possible that the primary reserve requirement needs to be changed for these regions.

Milligan, and others 2012). However, solar PV power output is a more direct energy conversion technology and can experience higher ramp rates. Furthermore, the impact of certain weather events, such as a storm front hitting a cluster of wind power plants, may need to be considered depending on the system characteristics.

IMPORTANT FOR:

- Systems with large VRE plants in concentrated areas

STUDIED IN:

- Portugal: Discovery that group of wind power plants tripped when there was a voltage dip led to the review of FRT in grid code

Secondary Response for Frequency Regulation

VRE power's most significant impacts on balancing affect "non-event" reserves, that is, regulation reserves (1–3 minutes) and load-following or market dispatch reserves (10–30 minutes). The impact on regulation reserves is lower compared with the impact on load-following reserves, however, because VRE power output forecasts improve the closer they are to real-time dispatch.

Therefore, the impact on secondary reserves is highly dependent on forecast accuracy and on how forecasts are considered in the scheduling and dispatch of regulation resources.

Ramp rates for wind power are still typically much lower than demand ramping rates (Holttinen, Milligan, and others 2012); therefore, a system that can adequately deal with demand ramping should also be able to accommodate VRE ramping.[15]

Tertiary Reserves for Balancing and "Slow Contingency" Events

Systems that balance supply and demand between gate closure time for market dispatch and regulation with some form of tertiary reserve[16] experience the largest impacts from VRE power output forecast errors. For such systems, it is crucial that reserve adequacy be assessed based on the type of forecast errors likely to be experienced.

At high VRE penetration levels, the aggregated variability and forecast error can potentially result in large but slow contingency events. For example, a large cloud or storm front could be expected to sweep across a solar PV plant or a wind power plant, respectively, causing a large discrepancy in expected supply and demand, but there could still be time to secure reserves. Therefore, it is important to identify these types of contingency situations based on the power system and assess the adequacy of corresponding reserves.

IMPORTANT FOR:

- Systems with high VRE penetration displacing synchronous generation
- Isolated systems with weak interconnection to neighboring systems (i.e. island systems)
- Systems with wind turbine generators connected via series compensated lines

STUDIED IN:

- Ireland: Minimum system inertia requirement has been implemented
- ERCOT: SSI has been observed on series compensated line

Stability

IMPORTANT FOR:

- Systems with high VRE penetration and weakly interconnected for frequency support

STUDIED IN:

- ERCOT: every 1 minute; every 5 minutes

Electromechanical Stability

Assess the impact on system inertia, transient response rotor-angle stability, small-signal oscillatory stability, and subsynchronous interaction.

The direct electromechanical impact of VRE is likely to be low (especially at low penetration) because most VRE power generators are connected via converters and are decoupled from the power system. The impact on system inertia is also likely to be low, except when VRE penetration

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[15] No studies into system-wide solar PV ramp rates have been found. Based on data from large plants on individual sites, solar PV ramp rates are much faster than wind ramp rates. Solar ramp rate characteristics would need to be studied separately.

[16] As in the United States, where there is unit commitment reserves.

is high[17] and VRE generation displaces a significant number of online synchronous generators. This situation is more likely to occur in small and isolated systems, for which electromechanical coupling to the neighboring network is weak. Furthermore, subsynchronous control interaction has been observed in some systems in which certain wind turbine converters are connected via series-compensated lines.

IMPORTANT FOR:

- Systems with HVDC lines

STUDIED IN:

- Ireland and New Zealand: General impact on system fault level was studied

Voltage Stability

Assess the impact of large disturbance (fault ride-through and post fault recovery), small variations (voltage control ancillary service, set point control, and dynamic reactive power support:

The impact of VRE on voltage stability depends primarily on the reactive power capability of two constituents, the VRE power plant, and the network to which the plant is connected. The degree to which a VRE power plant should contribute to voltage stability is usually dictated by a grid code, which may be common to all technology categories (as in Europe); specific to technology categories; or specific to each installation (as in Australia). Once the VRE power plant has fulfilled its obligations, the remaining support must be secured from the system, from either external reactive power devices or other conventional generators. The higher the VRE penetration, the fewer conventional generators will be online to offer voltage support; therefore, grid code requirements and system design must be based on accurate simulations of expected VRE power plant behavior and system behavior.

IMPORTANT FOR:

- Systems with high VRE penetration and weakly interconnected for frequency support

STUDIED IN:

- ERCOT: every 1 minute; every 5 minutes

Fault Level Adequacy for Operation of Protection Equipment and HVDC

When there is a short-circuit fault in a power system, protection equipment detects the fault current and isolates the fault location for a certain time to clear the fault. When a VRE power plant is added to the system, its contribution to the fault current generally decreases the overall fault level, and it is possible that the new fault level is beyond the range detectable by the protection equipment. Similarly, the fault level at the terminals of HVDC devices may drop below the level necessary for correct operation. The higher the VRE penetration, the fewer conventional generators will be online to contribute to fault current, thereby exacerbating the risk.

IMPORTANT FOR:

- Systems with high VRE penetration displacing synchronous generation
- Systems that are weakly interconnected for voltage support

STUDIED IN:

- Spain/Portugal: FRT requirements were revised in Grid Code based on voltage stability studies

Long-Term Planning

IMPORTANT FOR:

- Systems with VRE at remote areas of the network

STUDIED IN:

- ERCOT: Transmission infrastructure for the purpose of renewables integration have been identified based on Competitive Renewable Energy Zones (CREZ)
- EWIS: European-wide transmission study that identifies interim solutions to accommodate the increase in renewables until major transmission assets are built (which normally take up to 10-15 years to build)

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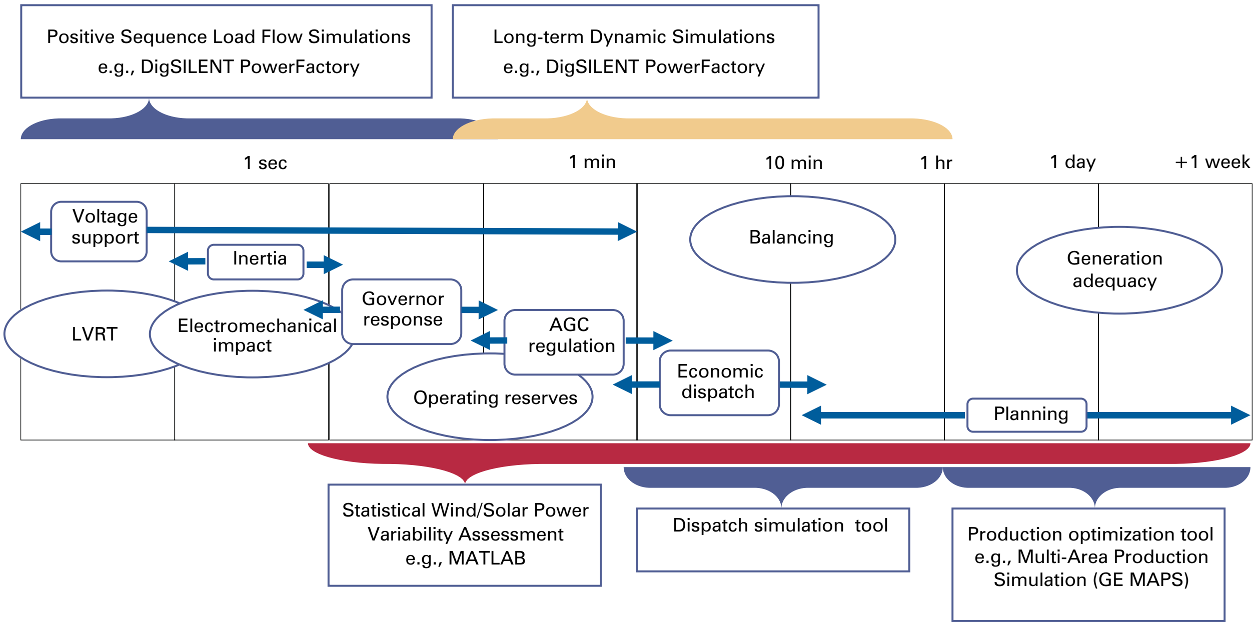
[17] This refers to the amount of online generation. For example, in Ireland, Bömer and others (2010) recommended that a maximum limit of 60 to 80 percent of "inertia-less" power (inverter-connected generation such as wind and solar PV) should be implemented to maintain sufficient system inertia.

Figure B2. Modeling Tools for Different Studies



Source: Adapted from [31] slide 10.

Generation Adequacy

Assess dependable capacity (capacity credit) or Effective Load Carrying Capacity (ELCC) impact on reliability standards.

The long-term reliability of the power system, that is, its ability to meet demand, can be compromised if the capacity contribution of VRE power is assessed inadequately in generation planning. Because VRE sources such as wind and solar irradiance are intermittent and difficult to predict, the quantity of energy that can be relied upon to be produced when needed is much lower than in conventional power plants. The uncertainty in production availability can be reduced somewhat by aggregating VRE sources across a wide geographic area, and by improving forecast accuracy. The dependable capacity contribution from VRE resources must be assessed as accurately as possible, particularly when high amounts of VRE are expected to replace retiring conventional power plants, so that supply security can be maintained at the required reliability level. Furthermore, underestimating the capacity contribution of VRE could cause oversizing of the required reserves which is economically inefficient.[18]

IMPORTANT FOR:

- Systems with high VRE penetration

STUDIED IN:

- IEA Task 25: Summary of methodologies used to assess VRE impact on generation adequacy based on review of prominent VRE integration studies
- Xcel Colorado40: Full reliability calculation based on +10 years of data
- Germany: ELCC estimated based on duration curves
- NYISO: Approximate method used based on assessment of VRE contribution during peak demand periods

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[18] http://www.nrel.gov/wind/systemsintegration/pdfs/colorado_public_service_windintegstudy.pdf.

Grid adequacy

Importance of a robust transmission design and proactive grid planning

Active and reactive power injected by new generation can change power flow characteristics and violate thermal or voltage limits. This is not unique to VRE power, however. When VRE resources are located farther from demand centers, as in the United States and Australia, it is more likely that the addition of VRE generation will result in congestion and cause voltage issues, particularly if large amounts of power are injected at the end of a long feeder in a radial fashion.

B.3. Assumptions and Model Requirements

Several methodologies can be used to study each of the issues described in section B.2. The methodology to adopt depends largely on the amount of data and resources that are available, as well as on the objective of the investigation. Common methodologies and models for each study are summarized in table B2. The models used in the studies—the transmission model as well as the generator and other component models—must be validated models. The use of models that have not been validated may lead to inaccurate simulation results, potentially causing security problems.

Figure B2 indicates the types of computer programs that could be used for analyzing each of the elements described.

Table B2. Common Methodologies and Models for Various Studies on Impact of VRE Integration

		Data requirements		
Element to be Assessed	**Method**	**Demand**	**Wind Power Generation**	**Nonwind generation**
Generation Adequacy	Assess whether the system can meet reliability standards with the addition of the estimated amount of VRE. To include VRE in the calculation process, use either capacity credit, or Effective Load Carrying Capacity (ELCC). The capacity credit or ELCC of VRE power can be estimated by either the reliability method or the approximate method. **Reliability method:** Calculate reliability metrics such as Loss of Load Expectation (LOLE), Loss of Load Probability (LOLP), and so forth, and compare reference case with VRE power integration case. **Approximate method:** Calculate average capacity factor corresponding to high demand periods. **Note:** The Reliability Method is preferred.	a) Historical demand (10+ years) Hourly or quarter-hourly historical demand profiles b) Defined high demand period based on analysis of historical demand	a) High/medium/low wind development scenarios (different distribution of wind power plants may be considered) Hourly or quarter-hourly historical wind power generation (may be developed from wind speed measurements, time-synchronized with demand) b) Wind power generation corresponding to high demand periods	a) Available generation capacity considering scheduled and forced outages. In areas with high hydro power penetration, reliable and firm energy availability of hydro resources must be taken into account. b) Not considered

(continued)

Table B2. Common Methodologies and Models for Various Studies on Impact of VRE Integration (continued)

		Data requirements		
Element to be Assessed	**Method**	**Demand**	**Wind Power Generation**	**Nonwind generation**
Grid Planning	a) **Steady-state power flow** simulations for (N) and (N–1) situations. b) **Time-synchronized dispatch** (market) simulation (analyses of inter-area flows and often compromised grid model).	a) Peak and off-peak demand b) Forecast demand (historical demand scaled to future)	Aggregated P&Q output of wind power plant based on fixed wind speed: a) For high and low wind power outputs b) Corresponding to the point in time analyzed	a) P&Q output model with full availability corresponding to the point in time analyzed, and external reactive power devices b) Available generation capacity considering scheduled and forced outages
Electromechanical stability	a) **Transient:** Dynamic power flow simulations following a 3-phase fault or sudden loss of a generating unit b) **Small-signal:** Modal analysis by eigenvalue calculation of small-signal stability with and without wind power c) **Subsynchronous:** Electromagnetic time domain simulations to evaluate the subsynchronous control interaction between the wind turbine converter and the HVDC link or series-compensated system	a) Peak and off-peak demand b) Appropriate static and dynamic load modeling c) Appropriate static and dynamic load modeling	a) High wind power output for aggregated WPP model, P&Q output based on fixed wind speed. Model must include corresponding low-voltage ride-through and reactive power support capability of WPP. b) Dynamic WPP models with voltage control mechanism, or assume constant mechanical torque. c) Electromagnetic time models of wind turbine generators. An aggregated model can be used.	a) Dynamic models of generators, external reactive power devices, and protection equipment b) Dynamic models of synchronous generators including excitation, speed governors, and power system stabilizers. External equipment for oscillation damping. c) Electromagnetic time model or HVDC link or series-compensated system and external devices providing reactive power support.
Fault level	Steady-state short circuit calculations (Electromagnetic transient simulations are performed for detailed connection studies)	Off-peak demand	Aggregated P&Q output based on fixed wind speed.	P&Q output model with full availability corresponding to the point in time analyzed, including external reactive power devices.
Inertia and frequency response	Dynamic frequency simulations following the sudden loss of generation	Off-peak demand	P&Q output based on fixed wind speed (high output level) Wind power plant features such as low voltage ride-through, reactive power support, and virtual inertia may be considered if expected to be implemented.	Dynamic models of generators, excitation, and speed governors

(continued)

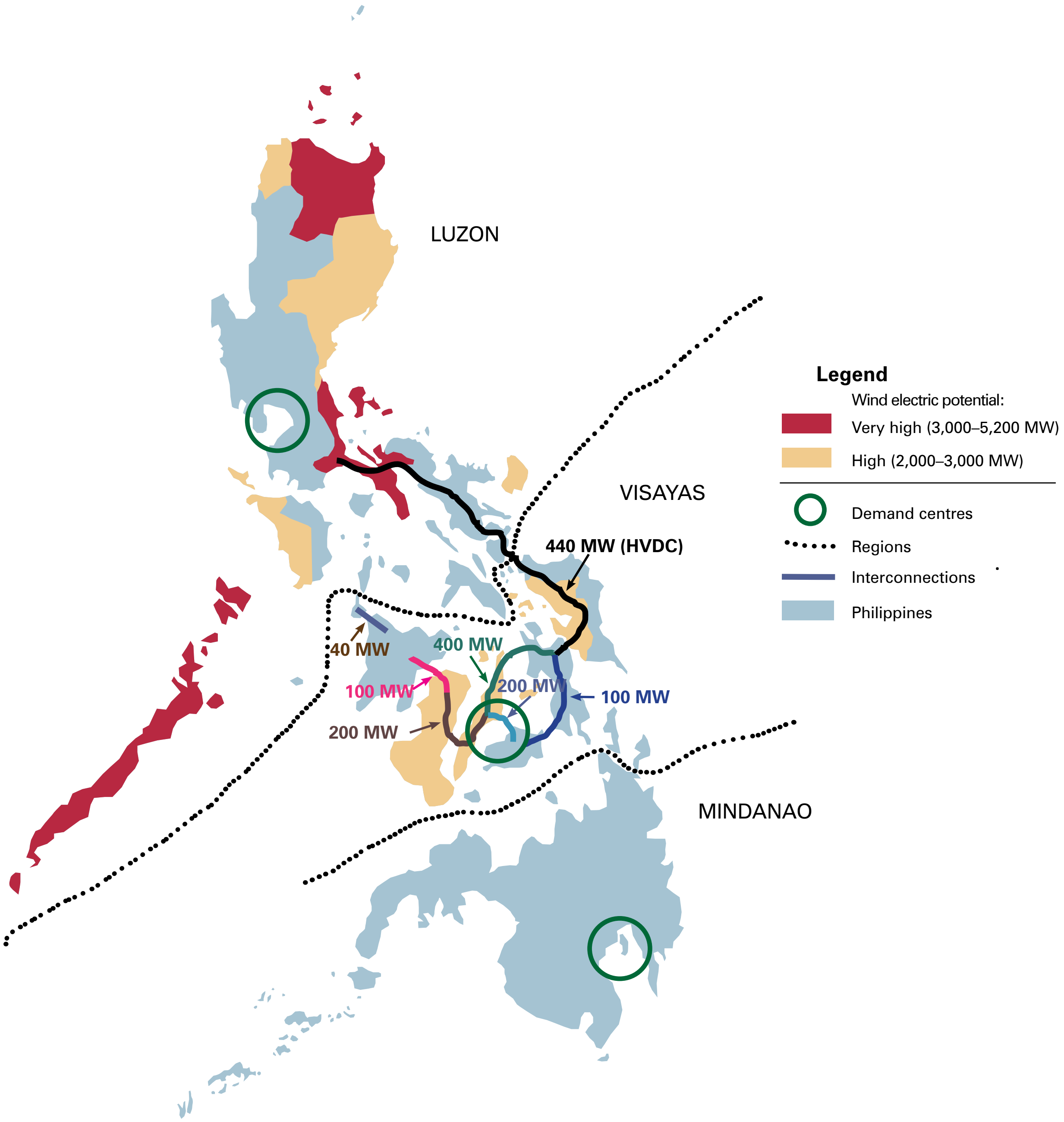
Table B2. Common Methodologies and Models for Various Studies on Impact of VRE Integration (continued)

		Data requirements		
Element to be Assessed	**Method**	**Demand**	**Wind Power Generation**	**Nonwind generation**
Balancing (regulation, dispatch, and short-term capacity)	**Statistical method:** Estimation of regulation reserve requirements based on the standard deviation of net load variability **Dispatch simulation:** Estimation of tertiary reserve requirements by time-synchronized simulation of the dispatch process The performance can also be evaluated according to the resulting carbon dioxide emissions, utilization rate of major interconnectors (if modeled), and curtailed amount of wind energy.	a) Historical demand on a minute basis (> 1 year) scaled to future level b) Historical demand on 5–30 minute basis (> 1 year) scaled to future level	a) Per minute wind power generation (time-synchronized with demand) based on historical wind speed measurements b) 5–30 minute wind power generation and output forecast values (time-synchronized with demand) based on historical wind speed measurements	a) Not considered b) Available generation capacity considering scheduled and forced outages. Conventional reserve availability characteristics (ramp rates, unit start-up and shut-down times, and so forth)
Voltage stability limits	Steady-state PV and QV analysis	Various load levels, representative data on voltage dependency	Model the behavior of the WPP at the point of connection considered. (For example in the case of New Zealand, WTGs must meet certain requirements with respect to minimum power factor, therefore WTGs were modeled as P&Q loads with unity power factor)	Various generation and dispatch scenarios. P&Q model with full availability corresponding to the point in time analyzed, including external reactive power devices.

Note: P&Q = active and reactive power; PV = photovoltaic; WPP = wind power plant; WTG = wind turbine generator.

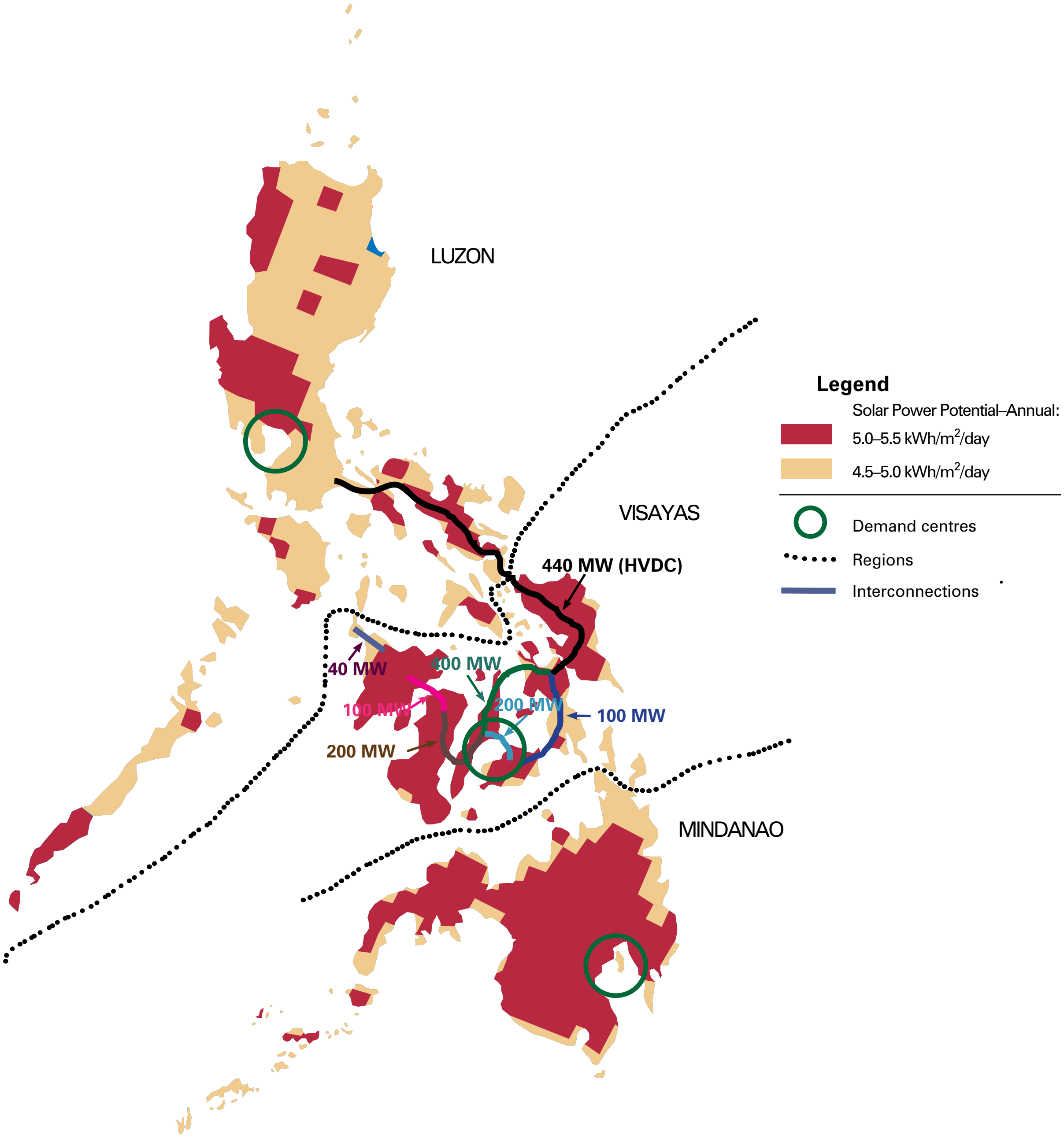
Appendix C. VRE Potential and Wind Contracts in the Philippines

Figure C1. Map of Interconnected Regions of the Philippines, Marked with Location of Demand Centers and Potential for Wind Power Development



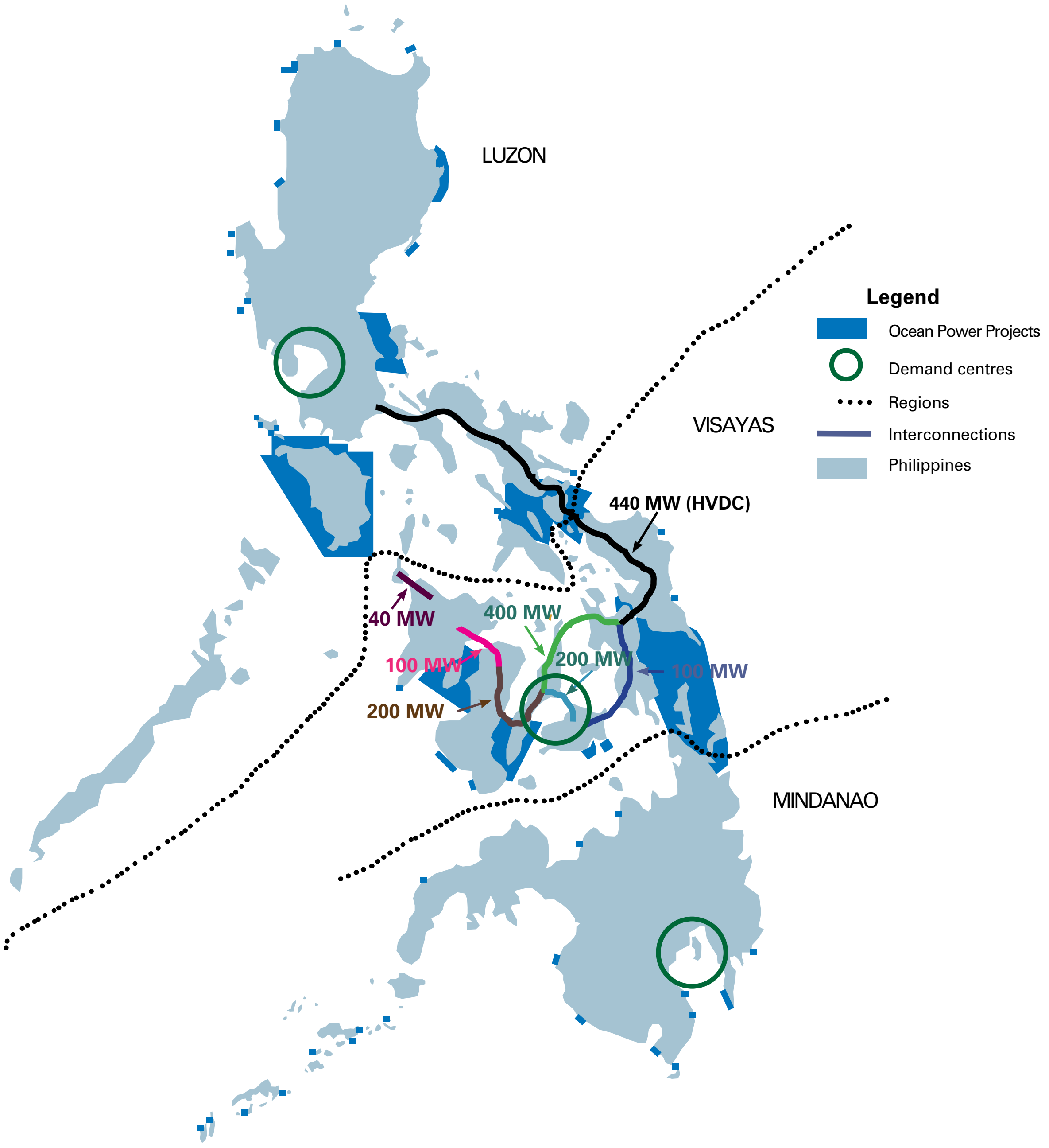
Source: Modified from [32] Page 69 and [5] page 101.

Figure C2. Map of Interconnected Regions of the Philippines, Marked with Location of Demand Centers and Potential for Solar Power Development



Source: Modified from [32] Page 69 and [6] page 9.

Figure C3. Map of Ocean Power Development



Source: [9] page 118.

Table C1. Wind Contracts in the Philippines

Grid/Region/Company Name/Location	Projected Capacity (MW)	Investment Cost (Php)
LUZON GRID	**748**	**332,226,378**
Region I	**326**	**136,797,510**
Alternergy Philippine Holdings Corporation	0	14,100,000
Sta. Praxedes, Cagayan & Pagudpud Wind Power Project	0	14,100,000
Energy Development Corporation	126	92,500,000
Balaoi-Pagudpud Wind Power Project	40	7,000,000
Burgos Wind Power Project	86	85,500,000
Energy Logics Philippines, Inc.	120	28,200,000
Pasuquin-Burgos Wind Power Project	120	28,200,000
Northern Luzon UPC Asia Corporation	30	974,215
Balaoi-Pagudpud Wind Power Project	30	974,215
Northern Luzon UPC Asia Corporation	50	1,023,295
Caparispisan-Pagudpud Wind Power Project	50	1,023,295
Region II	**190**	**89,458,488**
Alternergy Philippine Holdings Corporation	0	28,200,000
Aparri Wind Power Project	0	14,100,000
Sta. Ana Wind Power Project	0	14,100,000
FirstMaxpower International Corporation	45	21,075,000
Claveria Wind Power Project	15	7,025,000
Gonzaga Wind Power Project	15	7,025,000
Sanchez Mira Wind Power Project	15	7,025,000
NorthPoint Wind Power Development Corporation	40	8,282,898
Aparri-Buguey Wind Power Project	40	8,282,898
Trans-Asia Renewable Energy Corporation	105	31,900,590
Abulug-Ballesteros-Aparri Wind Power Project	45	10,696,305
Aparri-Camalaniugan-Buguey Wind Power Project	48	11,010,180
Sta. Ana Wind Power Project	12	10,194,105
Region III	**30**	**19,740,000**
PetroEnergy Resources Corporation	30	19,740,000
Sual Wind Power Project	30	19,740,000
Region IV-A	**111**	**44,667,840**
Alternergy Philippine Holdings Corporation	40	28,200,000
Lumban-Kalayaan Wind Power Project	0	14,100,000
Tanay-Pililla Wind Power Project	40	14,100,000
Trans-Asia Renewable Energy Corporation	71	16,467,840
Bauan-San Luis Wind Power Project	9	2,710,620
Calatagan Wind Power Project	10	2,710,620

(continued)

Table C1. Continued

Grid/Region/Company Name/Location	Projected Capacity (MW)	Investment Cost (Php)
Calauag Wind Power Project	10	2,838,195
Calauag-Lopez Wind Power Project	13	2,693,610
Infanta Wind Power Project	10	2,753,145
Silang Wind Power Project	19	2,761,650
Region IV-B	**40**	**21,100,000**
Alternergy Philippine Holdings Corporation	40	14,100,000
Abra de Ilog Wind Power Project	40	14,100,000
Energy Development Corporation	0	7,000,000
Taytay Wind Power Project	0	7,000,000
Region V	**36**	**13,197,540**
Trans-Asia Renewable Energy Corporation	36	13,197,540
Mercedes Wind Power Project	10	10,231,770
Paracale-Vinzons Wind Power Project	26	2,965,770
Region VI	**15**	**7,265,000**
First Maxpower International Corporation	15	7,265,000
Pulupandan Wind Power Project	15	7,265,000
VISAYAS GRID	**173**	**97,660,520**
Region VI	**21**	**7,057,170**
Constellation Energy Corporation	0	1,755,000
Ilog Wind Power Project	0	1,755,000
Trans-Asia Renewable Energy Corporation	21	5,302,170
Dumangas Wind Power Project	12	2,625,570
San Joaquin Wind Power Project	9	2,676,600
Region VII	**152**	**90,603,350**
Constellation Energy Corporation	0	1,755,000
Bayawan-Tanjay-Pamplona Wind Power Project	0	1,755,000
PetroEnergy Resources Corporation	30	19,740,000
Nabas Wind Power Project	30	19,740,000
Trans-Asia Renewable Energy Corporation	122	69,108,350
Anda-Guindulman Wind Power Project	10	2,710,620
Barotac Nuevo Wind Power Project	12	10,307,100
Ibajay Wind Power Project	10	10,219,215
Malay Wind Power Project	10	10,269,435
Nueva Valencia Wind Power Project	10	10,307,100
San Lorenzo Wind Power Project	54	15,038,000
Sibunag Wind Power Project	16	10,256,880
MINDANAO GRID	**0**	**21,000,000**

(continued)

Table C1. Continued

Grid/Region/Company Name/Location	Projected Capacity (MW)	Investment Cost (Php)
Region X	**0**	**7,000,000**
Energy Development Corporation	0	7,000,000
Camiguin Wind Power Project	0	7,000,000
Region XIII	**0**	**14,000,000**
Energy Development Corporation	0	14,000,000
Dinagat Wind Power Project	0	7,000,000
Siargao Wind Power Project	0	7,000,000
Grand Total	**921**	**450,886,898**
LUZON GRID	**0.006**	**0**
Region IV-A	**0.006**	**0**
DOST- Industrial Technology Development Institute	0.006	0
DOST-ITDI Wind Project	0.006	0
Grand Total	**0.006**	**0**
Solar Contract		
LUZON GRID	**1**	**750,000**
Region III	**1**	**750,000**
Aurora Special Economic Zone Authority	1	750,000
Casiguran Solar Power Project	1	750,000
Grand Total	**1**	**750,000**

Source: DoE 2010.

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