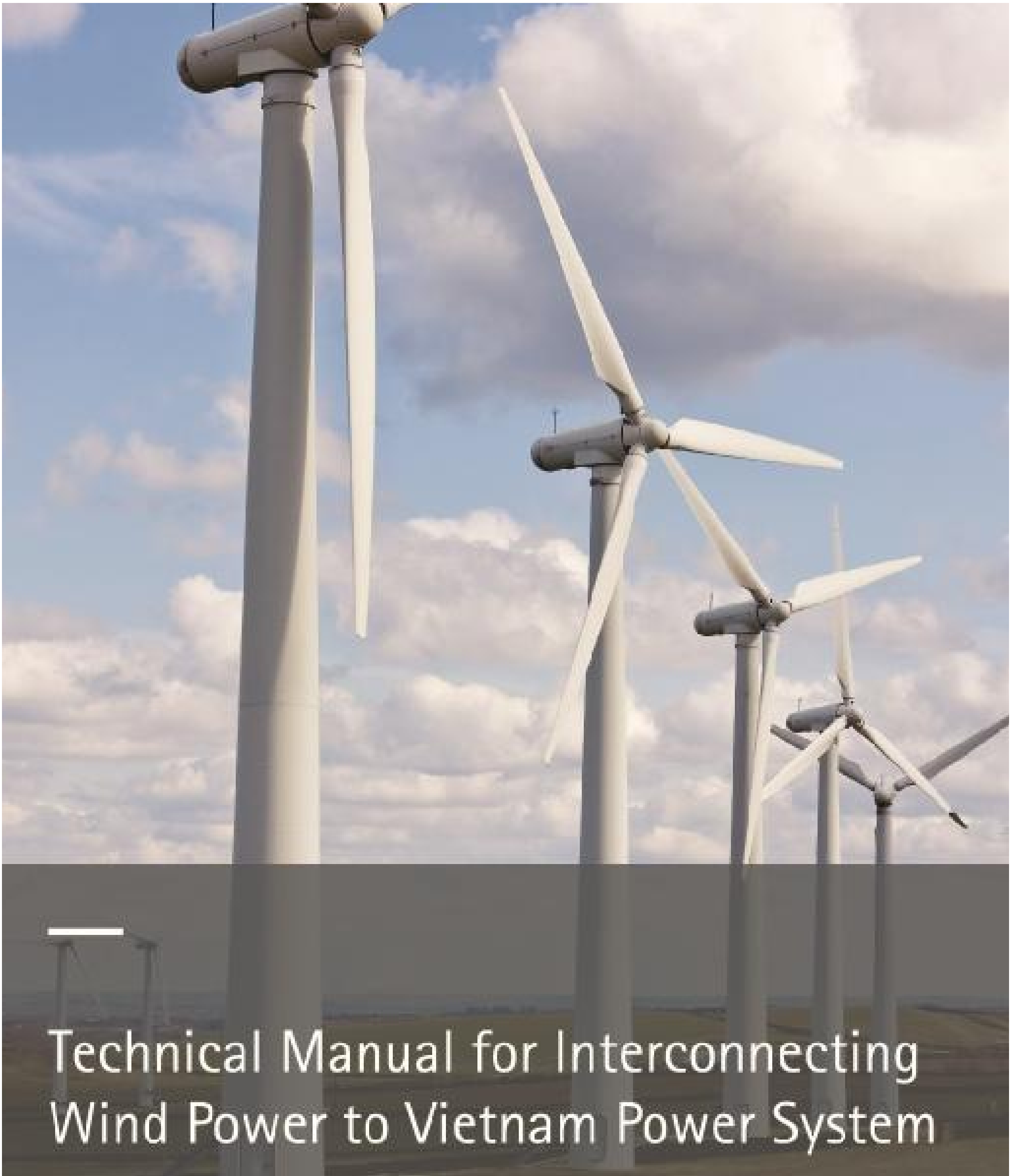

Technical Manual for Interconnecting Wind Power to Vietnam Power System

Cu International Copper Association Southeast Asia
Copper Alliance

EVN TẬP ĐOÀN ĐIỆN LỰC VIỆT NAM
VIETNAM ELECTRICITY

TECHNICAL MANUAL
FOR INTERCONNECTING WIND POWER
TO VIETNAM POWER SYSTEM

(For reference)

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Foreword

Vietnam is currently going through a period of energy thirst. Extreme effort is required in order to meet the fast-paced electricity demand which is forecasted to double approximately every five years. Meanwhile, fossil-based resources in Vietnam have been exploited close to their limits and massive import of these expensive resources is expected if no other types of generation are utilised to a good extent. On the other hand, the recent global greenhouse issue has inevitably caused a significant development in low carbon dioxide generation technology i.e. renewable energy.

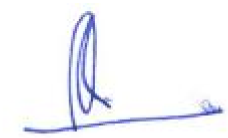
Vietnam prioritizes developing renewable energy resources such as wind power, solar power and biomass power. Projections are to increase the percentage of renewable energy power to 4.5 percent by 2020 and 6 percent by 2030.

Specifically, the plan aims to increase the combined capacity of all wind power plants to about 1,000MW by 2020 and 6,200MW by 2030.

However, the integration of a large amount of wind power into the national grid poses some challenging technical problems as compared to conventional power plant. This is due to the intermittent nature, generator technology and control concept of wind turbines.

Vietnam Electricity (EVN) and International Copper Association Southeast Asia Ltd (ICASEA) are pleased to present to you this manual on interconnecting wind power to the power system. The manual lays down the minimum technical requirements for the interconnection of wind power generation facilities to the transmission and distribution systems. The cooperation between EVN and ICASEA will deliver a small contribution to Vietnam wind power development.

It is therefore imperative for EVN and ICASEA to share good practices and knowledge through this technical manual with all audiences and bring wind power projects in Vietnam to higher standards of operation and development. We hope this manual will act as a first step towards a complete grid code for wind power in the *near future. We expect EVN-ICASEA partnership to grow and produce better results in the Vietnam power sector.*



Dang Hoang An
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Preface

International Copper Association Southeast Asia Ltd or ICASEA is the Southeast Asia arm of the International Copper Association (ICA). Headquartered in New York, ICA is a not-for-profit organization dedicated to promoting the correct application and efficient use of copper and copper-based solution.

ICASEA strategic initiatives include a portfolio of market development programs. The key objective of the *Southeast Asian Energy Access and Alternative Energy Program* is to increase copper consumption through higher uptake of renewable energy technologies in Southeast Asia. The program aims at the mitigation and removal of technical, policy and institutional, and market barriers towards the adoption of renewable energy technologies.

ICASEA is also a knowledge partner for upgrading of standards and skills of professionals in the industry.

A Memorandum of Agreement was signed between Vietnam Electricity (EVN) and ICASEA in Hanoi, Vietnam in May 2012. The general objective of the cooperation is to prepare for the integration of wind power to Vietnam's power system and evolving electricity market.

The study includes three components, namely: i) Recommendations for analysis of impacts of wind power integration on EVN power system; ii) Laying down interconnection standards for wind power generation plants; and iii) Recommendations for integration of wind power generation under a competitive electricity market structure.

A key output of this collaboration is the production and publication of this Technical Manual for Interconnecting Wind Power to Vietnam Power System. The technical manual has been commented and reviewed at the stakeholders' consultation workshop on December 4, 2012.

Beyond the production and publication of this technical manual, EVN and ICASEA will continue to collaborate for the immediate and effective implementation of the technical manual and development of the Vietnam wind grid regulation (code) in 2013 and 2014.

Acknowledgements

EVN and ICASEA acknowledge the active participation and expert contributions of national and regional technical experts during the consultation workshop on December 4, 2012 and their valuable comments on the draft technical manual.

These experts represent the following agencies and organizations:

- Electricity Regulatory Authority of Vietnam
- Department of New energy and Renewable Energy
- National Load Dispatching Centre
- Institute of Energy
- Hanoi University of Science and Technology
- Hanoi Electric Power University
- Vestas Wind Systems A/S Company
- Green Innovation and Development Centre
- Vietnam Electrical Engineering Association
- Power Engineering Consulting Joint Stock Company 1
- VICODE
- EVN Electric Information Centre
- Southern Power Corporation
- Central Power Corporation
- Cong Ly Company
- RE Limited Company of PV Power
- Petro Vietnam
- Nordic Chamber of Commerce.

EVN and ICASEA also recognize the contribution of Resource Management Associates (Pvt) Ltd. Sri Lanka (RMA) with the support of the national consultant, Power Engineering and Consultancy Company No. 3 (PECC3) in conducting the studies and drafting this technical manual.

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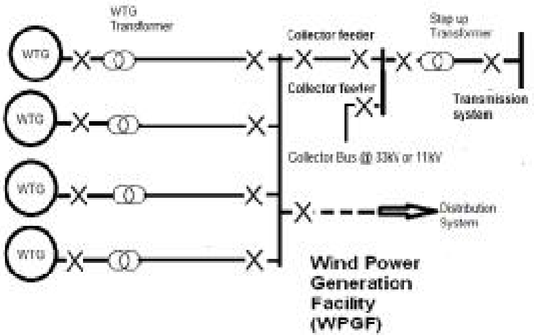
Definitions and Abbreviations

Active Power or MW	Product of voltage and current and cosine of the phase angle between them measured in units of: • Watt (W) • kilowatt (kW) = 10^3 W • Mega Watt (MW) = 10^6 W • Giga Watt (GW) = 10^9 W • Tera Watt (TW) = 10^{12} W
Active Energy	The electrical energy produced, flowing or supplied by an electrical circuit during a time interval, being the integral with respect to time of Active Power, measured in units of watt-hours or standard multiples thereof, that is : 1000 Wh = 1kWh; 1000 kWh = 1MWh 1000 MWh = 1GWh; 1000 GWh = 1 TWh = 10^{12} Wh
A.C.	Alternating current
Apparent Power	S = P + JQ. Magnitude is calculated by the formula S = √(P2 + Q2) expressed in units of Volt-amps (VA) or multiples like kVA, MVA
Auto reclosing	The automatic reclosure of a circuit-breaker after a predetermined time following a fault tripping
Auxiliary	Pumps, motors and other similar equipment required to operate in a WPGF to enable a WPGF to be operational
Circular 12	Circular 12/2010/TT-BCT issued by the Ministry of Industry and Trade of Vietnam
Circular 32	Circular 32/2010/TT-BCT issued by the Ministry of Industry and Trade of Vietnam
Collector bus	The bus to which the high voltage side terminals of WTG stepping up transformers are connected to, which in turn is connected to the low voltage side of the transmission system stepping up transformer, through collector feeders
Connection agreement	The agreement between TNO/DNO and a WPGF to connect latter's generation facilities to a transmission/distribution network
Connection point	Highest voltage point at which electric energy is transferred between a WPGF and the distribution or transmission network. This can be a Point of Supply (POS), Point of Delivery (POD) or both
Current transformer (CT)	An instrument transformer in which the primary winding is connected in series with the circuit whose current is to be measured or monitored and the secondary current is substantially proportional to the primary current under normal conditions of operation
DMS	Distribution Management Systems
Distribution network operator (DNO)	A person who is licensed to carry out electricity distribution activities in accordance with the License agreement
Distribution system	The system consisting of lines and switchgear owned and/or operated at a voltage equal to or lower than 110kV, by a Distribution Licensee for the purposes of distribution of electricity from a grid substation to another substation, or to or from any external interconnection, or to deliver to customers, including any plant and apparatus and meters owned or used by the Distribution Licensee in connection with the distribution of electricity
Doubly fed induction generator	An induction generator that operates with an alternating electrical supply connected to both the stator and rotor winding the supply to which is modified using power electronic circuitry
Earthing	A way of providing a connection between conductors and/or apparatus already connected to the transmission system/distribution system
Embedded generator	A single generator, or a group of generators, connected to the DNO's distribution network
EMS	Energy Management System
Extra high voltage	Nominal voltage level exceeding 220kV
Flicker severity	The value derived from 12 successive measurements of Flicker Severity (Short Term) over a two-hour period calculated by the formula

(Long term) P_{lt}	$$P_{lt} = \sqrt[3]{\frac{1}{12} * \sum_{j=1}^{12} P_{stj}^{3}}$$
Flicker severity (Short term) P_{st}	Measurement value within ten (10) minutes period by the flicker meter in accordance with IEC868
Frequency	Number of alternating current cycles per second (expressed in Hertz Hz), at which the transmission system/distribution system is running
Harmonics	Sinusoidal voltages and currents having frequencies that are integral multiples of the fundamental frequency
High voltage	Nominal voltage level exceeding 35kV up to 220kV
Induction generator/Asynchronous generator	A machine that uses the principles of an induction motor to produce electric power, thus performing as an alternating-current generator, when its rotor is driven by a prime mover to turn faster than the synchronous speed , giving a negative slip.
Islanding	The process whereby a power system is separated into two or more parts, with generators supplying loads connected to some of the separated systems.
Low voltage	Nominal voltage level under 1000V
Low voltage ride through (LVRT)	Capability of a WPGF to ride through low voltage caused by a system disturbance
Medium voltage	Nominal voltage level from 1000 V up to 35kV
Metering equipment	Equipment including meters, current transformers, voltage transformers and auxiliary equipment for power measurement
Metering system	Equipment and circuits installed to measure the quantity of electricity exported/imported through a connection point
Neutral point displacement voltage	The voltage between the real or virtual neutral point and the earth
Neutral voltage displacement (NVD)	A technique to measure the displacement of the neutral voltage with respect to earth
Power factor	Ratio of active power (kW) to apparent power (kVA)
Protection	Provisions for detecting abnormal conditions on a System and initiating fault clearance and activating alarms and indications
Reactive Power or MVAr	The product of voltage and current and the sine of the phase angle between them measured in units of volt-amperes reactive (VAr) and standard multiples thereof
Reactive power capability chart	Diagram showing the MW and MVAR Capability limits within which a WPGF is expected to operate under steady state conditions in the manner prescribed by the manufacturer. The diagram shall indicate the output under different power factors
RTD	Resistance Temperature Detector
SO	System Operator
SCADA system	A real time control and monitoring system in which the control and data collection functions in respect of the power system are carried out from a central station through a communications system
Transmission network	The entire inter-connected electric power transmission network of Vietnam consisting of 110kV and 220kV lines owned and/or operated by the TNO for the purpose of the transmission of electricity from a Power Station to a Substation or to another Power Station or between Substations or to or from any External Interconnection including any plant and Apparatus and meters owned or used by the transmission licensee
Transmission network operator/owner (TNO)	A person who is licensed to carry out transmission activities, responsible for expansion, maintenance, managing and operating the national transmission grid
User	An organization, individual, who uses the Transmission system or Distribution system
Voltage fluctuation	Changing of voltage amplitude above or below the nominal value of voltage in a defined period

Voltage level	One of the nominal voltages at which a power system is operated at
Voltage regulatory system	A centralized control system at a WPGF that measures voltage compared to a set point voltage and controls reactive power devices
Voltage transformer (VT)	An instrument transformer whose primary winding is connected in parallel with the circuit whose voltage is to be measured or monitored and the secondary voltage is substantially proportional to the primary voltage under normal conditions of operation
Wind power generation facility	An installation where one or more WTGs are connected a. to a transmission network using individual WTG step up transformers, a collector system/s operated at medium voltage and medium voltage/high voltage transformer/s or b. to a distribution network using individual WTG step up transformer/s, with or without a collector 
Wind turbine generator (WTG)	A device that converts kinetic energy from the wind into electrical energy, which can be either synchronous or asynchronous

1 INTRODUCTION

1.1 Background

The Ministry of Industry and Trade issued Circulars No. 12/2010/TT-BCT and No. 32/2010/TT-BCT (hereafter referred to as “Circular 12” and “Circular 32” respectively) to specify criteria, guidelines, basic rules, procedures, responsibilities, standards and obligations for the operation, maintenance and development of Vietnam Electricity’s power generation, transmission and distribution systems. Vietnam Electricity, also called EVN, is a government corporation that owns and operates the country’s largest and main power company.

With the Vietnam electricity industry due to be transformed to a wholesale model based structure by 2014, and considering EVN’s plans to facilitate the interconnection of wind energy resources to its existing system, it has become necessary to modify Circulars 12 and 32 to ensure the:

a. smooth integration of wind power generation facilities (WPGFs) into the transmission and distribution systems,
b. reliable and secure operation of the existing and new WPGFs
c. performance of the WPGFs that will adhere to specified standards and
d. continued operation of the present transmission and distribution systems in compliance with the power system performance standards already stipulated in Circular 12 and the Circular 32, even after wind power generation integration

1.2 Purpose

This manual, as a reference, establishes the minimum technical requirements for WPGFs that *will be* connected to the EVN transmission and distribution systems. Interested applicants seeking connection to the transmission network or distribution network should be required to comply with these technical requirements. All transmission and distribution network operators should likewise follow the guidelines given in this manual in relation to the planning and connection of such WPGFs.

1.3 Limitations

In the absence of dynamic studies on wind integration, certain definite maximum levels for wind penetration and WPGF capacities are assumed. Thus the technical requirements and guidelines stipulated here will have to be revised and amended if and when the wind penetration or wind farm capacities exceed the levels so assumed or as the transmission and distribution networks develop further, to comply with good industry practices and standards.

2 WIND ENERGY DEVELOPMENT

2.1 Wind Energy Development Program

The government's wind power development plan has set targets to develop 1000 MW by 2020, and 6,200 MW by 2030. Table 1 shows the wind power outlook up to 2030. As can be seen, wind power will be a fraction of the total installed capacity and mainly developed in the Binh Thuan province.

Table 1 - Wind Power Outlook

Year	2011	2020	2030
Total wind power installed capacity (MW)	30	1,000	6,200
Wind power in Binh Thuan province (MW)		700	2500
System installed capacity (MW)	21,000	66,979	137,000
Wind power : System capacity	0.14%	1.5%	4.5%
Wind power: Renewable capacity	5.3%	22.3%	39.2%
Wind power: Maximum demand	0.16%	1.9%	5.6%
Wind power: Minimum demand	0.25%	3.0%*	8.7%*

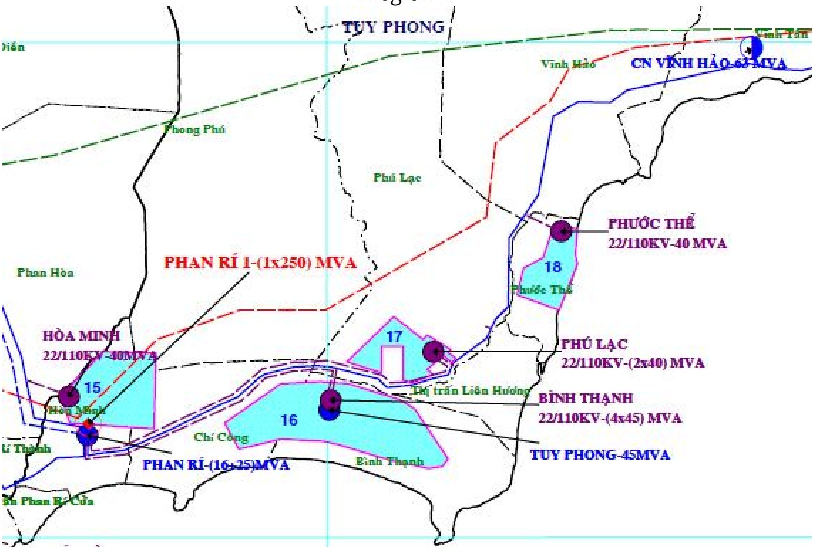
** Assuming the maximum demand, minimum demand ratio is same as 2011*
Source: Tran,Trung Nam. Overview of the Vietnamese Power System. September 2012.

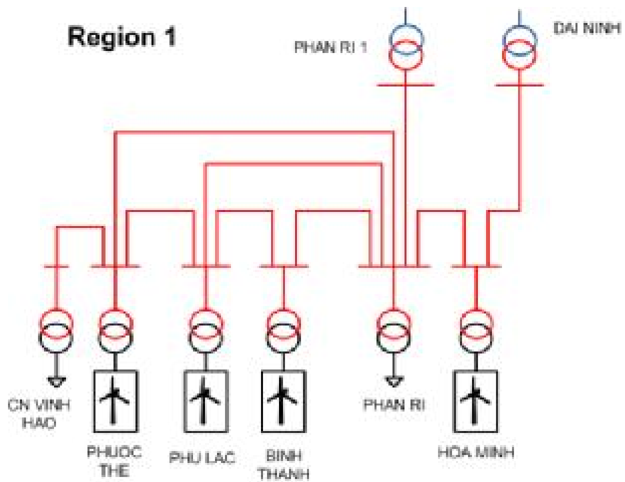
The Power Engineering and Consultancy Company No. 3 (PECC3) carried out a wind power plan for Binh Thuan province from 2009 to 2015, with a vision for 2020. Twenty wind farms were identified as feasible by this study and details of the wind farms in these regions with high wind potential are shown in Table 2. These twenty farms are proposed to be connected through 110kV and 22 kV substations.

Figure 1 shows the capacity and distance to the nearest 110 kV line for each wind farm and it could be seen that the distance from each wind farm to the grid is between 1 to 5 kilometers for majority of the identified wind farms. The longest connection distance to 110 kV line is for Hoa Thang 3 wind farm, equal to 10.2 km.

Table 2 - Proposed Wind Power Developments in Binh Thuan Province and Single Line Diagrams

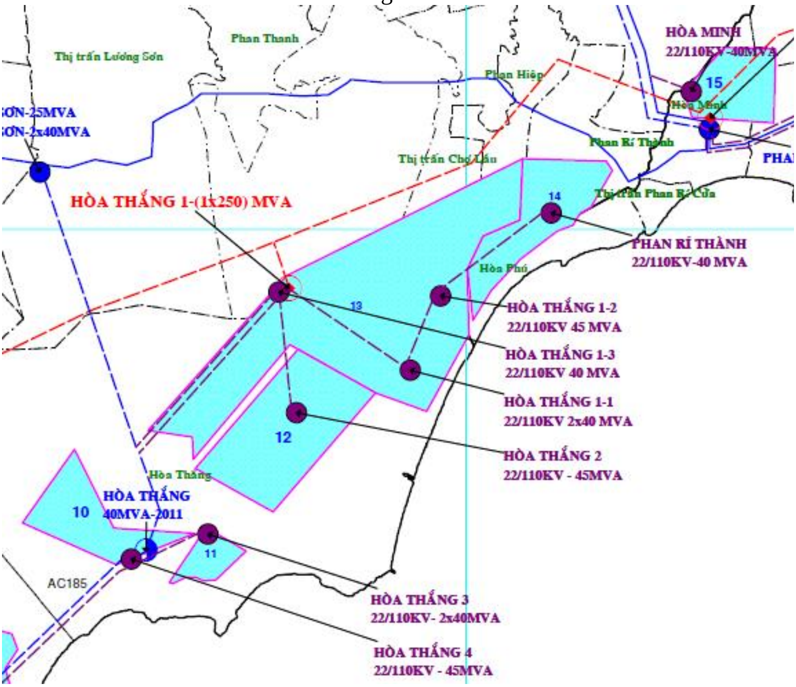
Region 1



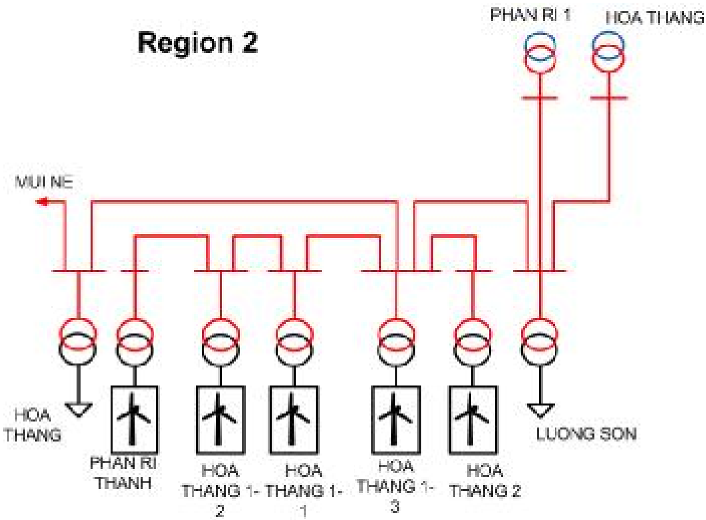


Source: Binh Thuan Wind Power Development Map and PSS/E studies. s.l.: PECC3.

Region 2



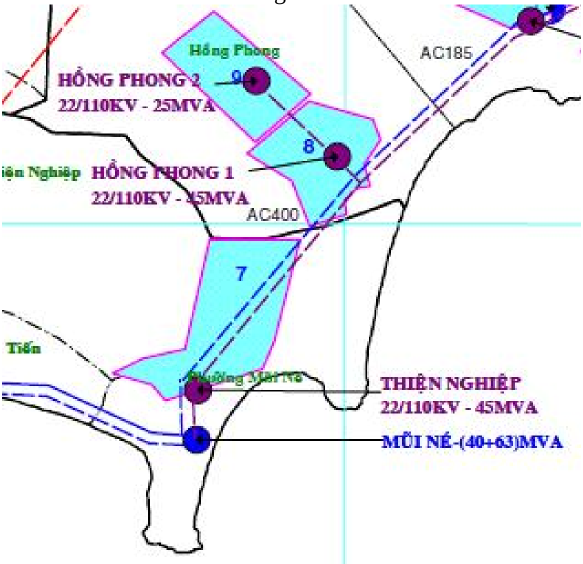
Phan Thanh
Thị trấn Lương Sơn
Phan Hiệp
HÒA MINH
22/110KV-40MVA
15
Hòa Minh
Phan Rí Thành
Thị trấn Chợ Lầu
HÒA THẮNG 1-(1x250) MVA
14
Thị trấn Phan Rí Cửa
PHAN RÍ THÀNH
22/110KV-40 MVA
Hòa Phú
13
HÒA THẮNG 1-2
22/110KV 45 MVA
HÒA THẮNG 1-3
22/110KV 40 MVA
HÒA THẮNG 1-1
22/110KV 2x40 MVA
12
HÒA THẮNG 2
22/110KV - 45MVA
Hòa Thắng
HÒA THẮNG
40MVA-2011
10
11
AC185
HÒA THẮNG 3
22/110KV- 2x40MVA
HÒA THẮNG 4
22/110KV - 45MVA

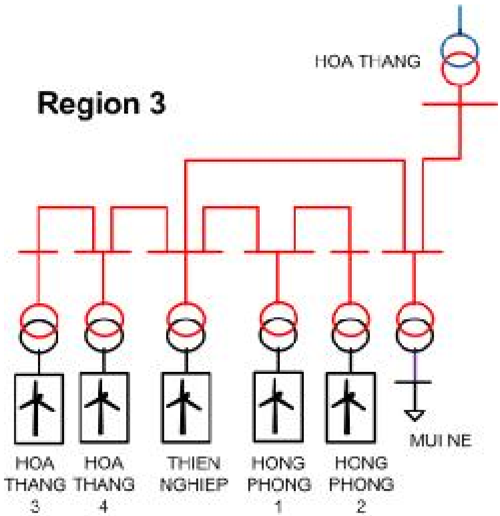


Region 2
PHAN RI 1
HOA THANG
MUI NE
HOA THANG
PHAN RI THANH
HOA THANG 1-2
HOA THANG 1-1
HOA THANG 1-3
HOA THANG 2
LUONG SON

Source: Binh Thuan Wind Power Development Map and PSS/E studies. s.l.: PECC3.

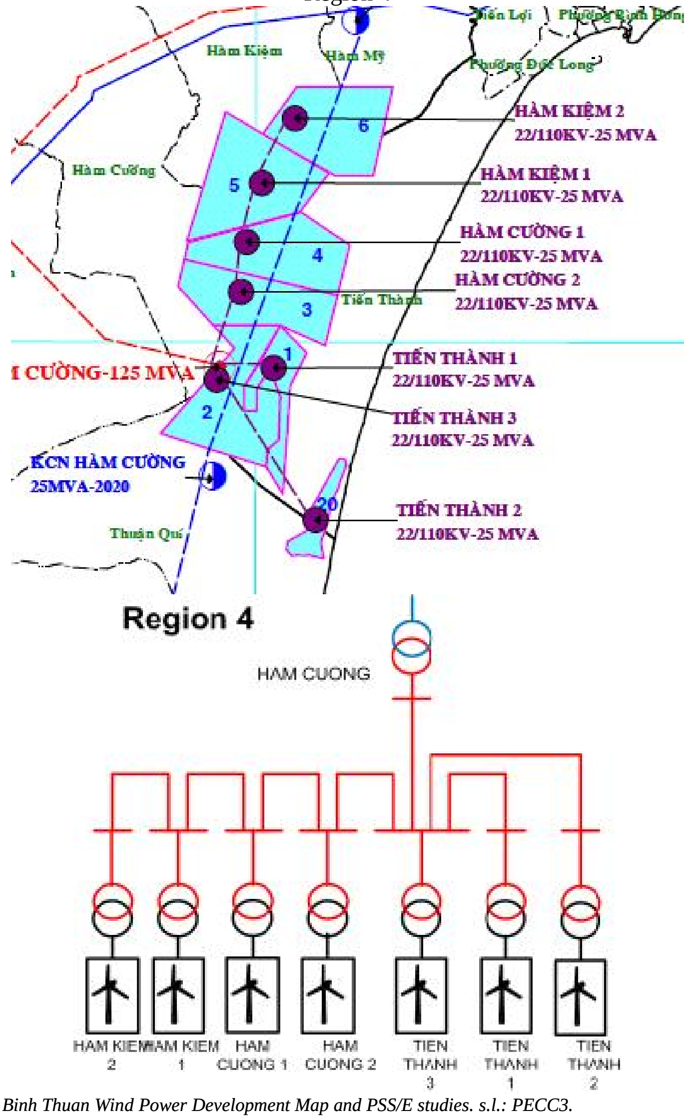
Region 3





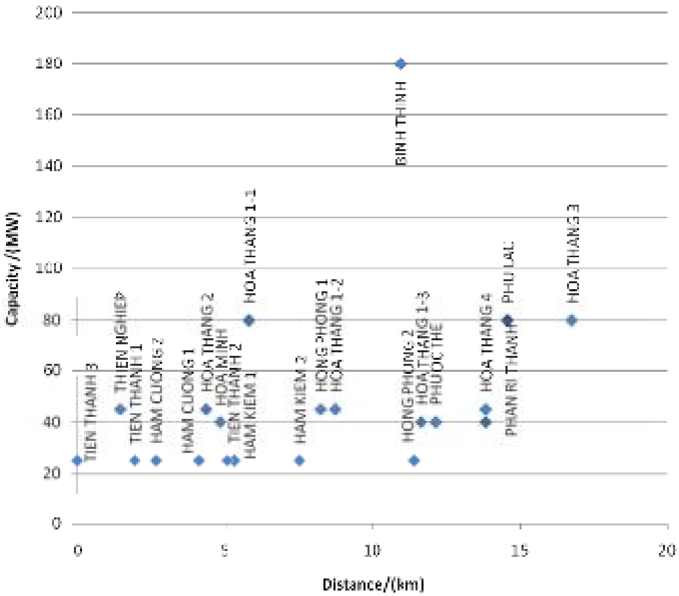
Source: Binh Thuan Wind Power Development Map and PSS/E studies. s.l.: PECC3.

Region 4



Source: Binh Thuan Wind Power Development Map and PSS/E studies. s.l.: PECC3.

Figure 1 - Size and Connection Distance of Each Wind Farm

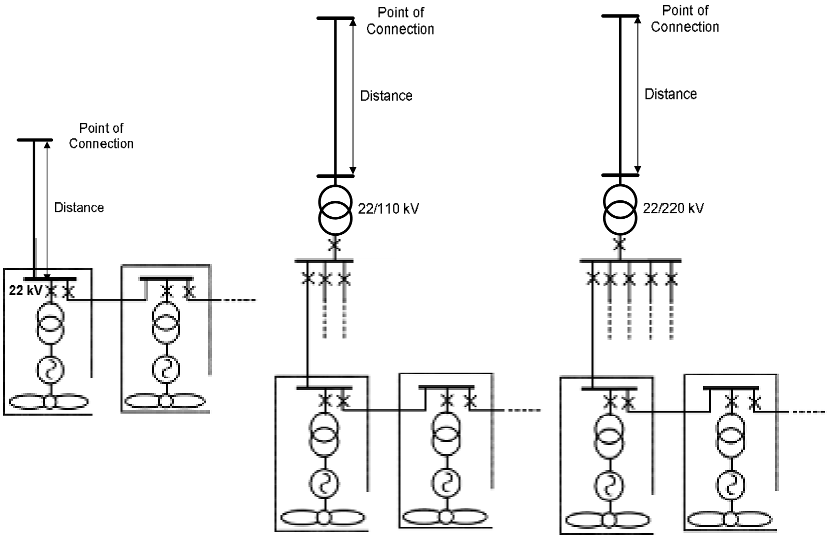


Source: PECC3, Provincial Wind Power Development Plan Binh Thuan 2011-2020, Vision 2030.

2.2 Wind Farm Connections

In order to assess the appropriate voltage levels of each anticipated wind power facility, the connection topologies shown in Figure 2 was considered. These connection arrangements are based on the existing studies carried out for Binh Thuan province.

Figure 2 - Possible Wind Farm Connection Topologies



Small wind farm	Medium size wind farm	Large wind farm
Capacity ≤ P_1	P_1 < Capacity ≤ P_2	P_2 < Capacity

A flowchart was developed, given in Figure 12, as guide to determine such voltage levels, and the data used for the calculations are given in Table 3 and Table 4.

Table 3 - Costs Used for Wind Farm Connection Assessment

Item	Voltage level	Unit	Unit Cost ($)
Double circuit overhead line	22 kV	Km	27,091 – 37,385
	110 kV		177,885
	220 kV		341,346
Single circuit overhead line	22 kV	km	17,135 - 22,894
	110 kV		120,192
	220 kV		235,577
Substation	22/110 kV, 25 MVA		2,888,615
	22/110 kV, 40 MVA		2,644,231
	22/110 kV, 63 MVA		2,403,846
	110/220 kV, 125 MVA		7,403,846
	110/220 kV, 250 MVA		10,480,769

Source: Interview with PECC3

Table 4 - Line Parameters Used

Voltage level (kV)	Conductor cross sectional area (mm^2)	R (Ω/km)	X (Ω/km)
22	185	0.1576	0.1965
110	240	0.0674	0.2054
220	400	0.1113	0.2114

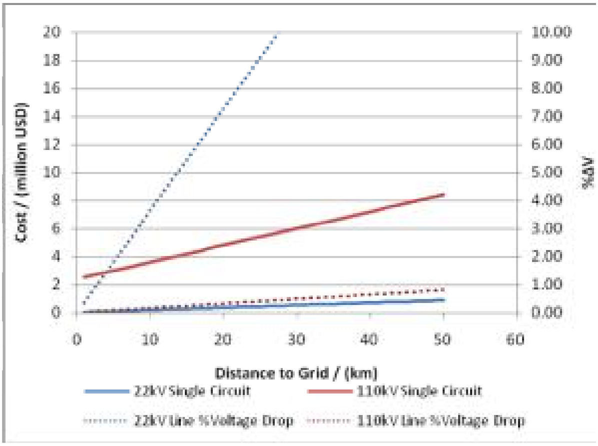
Figure 3 shows the effect of power level and distance on the cost and voltage drop of a small wind farm interconnection. In Figure 3, thick lines show the cost and dotted lines show the percentage voltage drop across the line. As can be seen from Figure 3(a), a single circuit 22 kV line is more economical for a wind farm of capacity 10 MW, provided that the distance from the wind farm bus to the point of connection is less than 14 km.

Beyond this distance, the voltage drop becomes more than 5%, thus demanding a double circuit line. Figure 3(b) shows the cost and voltage drop associated with a 19 MW wind farm interconnection. In this case, a 22 kV double circuit line can be used up to a distance of about 15 km; beyond which a 110 kV connection is required.

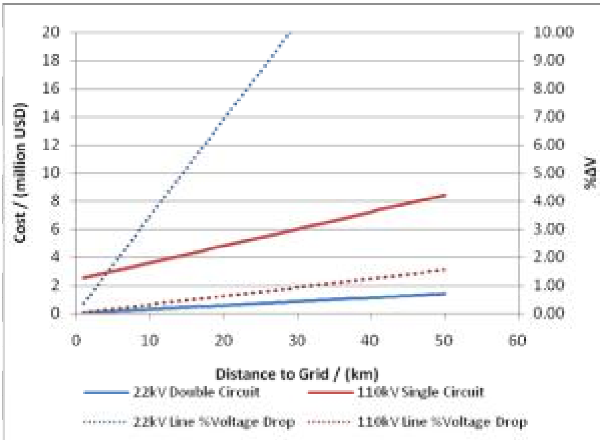
Similar assessment was carried out for a medium scale wind farm. Figure 4(a) shows the cost and voltage drop associated with a 100 MW wind farm. In this case, a 110 kV single circuit line can be used up to a distance of about 48 km; beyond this a 110 kV double circuit must be employed.

Similarly from Figure 4(b), a double circuit 110 kV line can be used for a wind farm of capacity 200 MW provided that the distance from wind farm bus to the point of connection is less than 48 km. Beyond this distance, the voltage drop becomes more than 5%, thus requiring a 220 kV connection. It was found that if the wind farm capacity is greater than 200 MW, a 110 kV 240 mm^2 double circuit line cannot be used, thus requiring a 220 kV connection.

Figure 3 - Interconnection Costs and Voltage Drops Associated with 10MW(a) and 19MW Wind Farms(b)



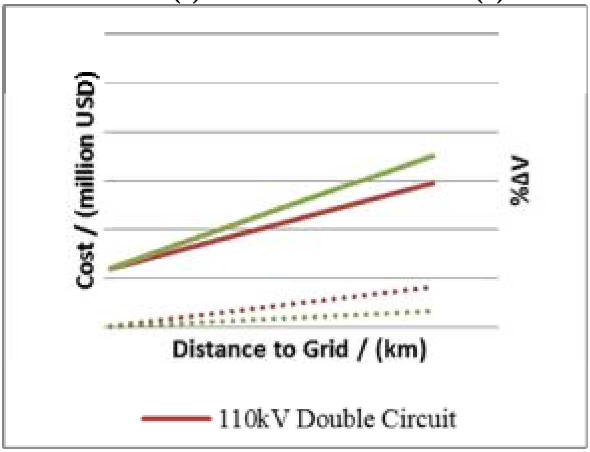
(a) 10 MW wind farm



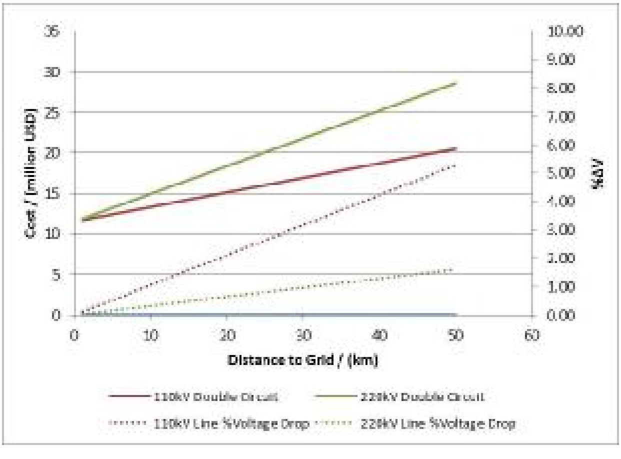
(b) 19 MW wind farm

Source: Generated by Resource Management Associates

Figure 4 - Interconnection Costs and Voltage Drops Associated with 100MW (a) and 200MW Wind Farms (b)



(a) 100 MW wind farm



(b) 200 MW wind farm

Source: Generated by Resource Management Associates

The summary of these findings is given in Table 5.

Table 5 - Determination of Voltage Levels / Circuit Types for Connection of Wind Farms

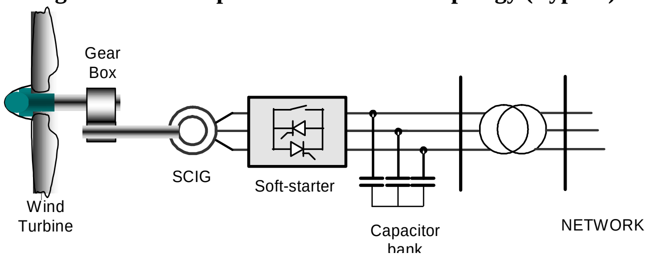
Wind farm capacity (MW)	Maximum allowable voltage drop	Distance to the POC from wind farm bus (km)	Voltage level and the circuit type
≤ 10	5%	≤ 14	22kV Single circuit 185 mm^2
		>14	22kV Double circuit 185 mm^2
>10 and ≤ 19		≤ 15	22kV Double circuit 185 mm^2
		>15	110kV Single circuit 240 mm^2
>19 and ≤ 100		≤ 48	110kV Single circuit 240 mm^2
		>48	110kV Double circuit 240 mm^2
>100 and ≤ 200		≤ 48	110kV Double circuit 240 mm^2
		>48	220kV Double circuit 400 mm^2

APPENDIX TO SECTION 2

2.A. Brief Introduction to Different Types of Wind Turbines

The existing wind generator technologies are classified into four different types, such as Types A, B, C and D (Ackermann, 2005). Type A is the fixed speed wind generator which is commonly known as fixed-speed induction generator (FSIG). FSIG employs a squirrel cage induction generator as shown in Figure 5 - . As the generator operates at a super-synchronous speed with a slip of 1 to 2%, essentially the speed can be considered as constant or fixed. The FSIG absorbs reactive power to set up its magnetic field. In order to minimise the burden on the network to which the generator is connected, a capacitor bank is provided to supply a part of the reactive power requirement of the generator.

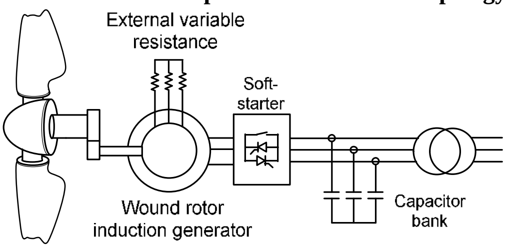
Figure 5 - Fixed Speed Wind Turbine Topology (Type A)



Source: Olimpo et al, Wind Energy Generation: Modelling and Control, 2009.

Type B is the limited variable speed wind generator and shown in Figure 6. This employs a wound rotor induction generator and an external variable resistor is connected to the rotor circuit. The external resistor is electronically controllable and is mounted on the rotor. This eliminates the need for high current slip rings and brushes. However, the market penetration of type B technology is low compared with the other wind generator technologies. (Hansen & Hansen, 2007).

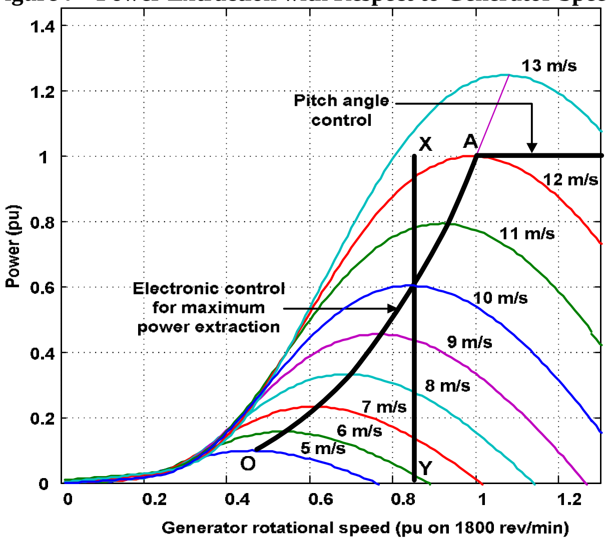
Figure 6 - Limited Variable Speed Wind Turbine Topology (Type B)



Source: Olimpo et al, Wind Energy Generation: Modelling and Control, 2009.

As shown in Figure 7, in order to extract maximum power at various wind speeds, the generator speed should vary along curve OA. However as the fixed speed wind generator operates along curve XY, it cannot extract the maximum available power from wind. In order to drive the machine along curve OA, the generator speed should vary with the wind speed, and this is normally achieved by employing power electronic interfaces or controllers. Commonly used topologies for variable speed operation of wind turbines are the doubly-fed induction generator classified as type C and full power converter wind generator (FPC) classified as type D.

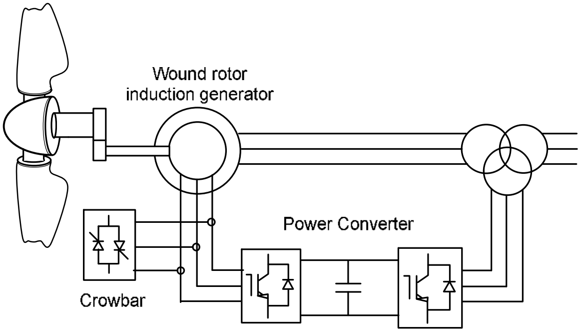
Figure 7 - Power Extraction with Respect to Generator Speed



Source: Olimpo et al, Wind Energy Generation: Modelling and Control, 2009.

The doubly-fed induction generator is constructed from a wound rotor induction generator as shown in Figure 8. Variable speed operation is obtained by injecting a variable voltage into the rotor at slip frequency. The injected rotor voltage is obtained using two four-quadrant ac/dc IGBT-based voltage source converters (VSC), linked by a DC bus.

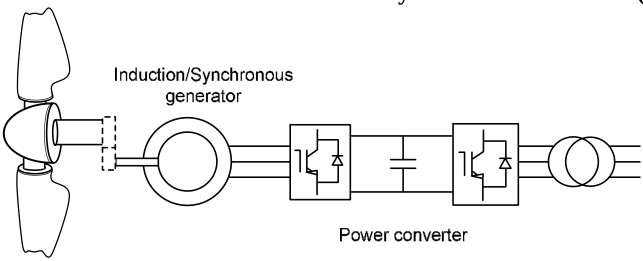
Figure 8 - Doubly-Fed Induction Generator Topology (Type C)



Source: Olimpo et al, Wind Energy Generation: Modelling and Control, 2009.

An FPC wind turbine, shown in Figure 9, has an induction/synchronous generator, and power electronic interface. A power electronic interface connected in series transforms variable-frequency ac power generated by the generator into fixed-frequency ac power. This scheme offers less harmonic distortion and unity displacement factor operation.

Figure 9 - FPC Wind Turbine with Induction/Synchronous Generator (Type D)



Source: Olimpo et al, Wind Energy Generation: Modelling and Control, 2009.

2.B. Wind Turbines Currently Operating in Vietnam and Regional Trends

All the large wind turbines operating in Vietnam are Type C. Wind turbines operating in Tuy Phong wind farm are Furhlaender Model FLMD 77 with a capacity of 1.5 MW. The wind farm in Bac Lieu Province utilizes 1.6 MW GE wind turbines. Vestas supplied 3 turbines of capacity 2 MW for the PV Power Project in Phu Quy Island.

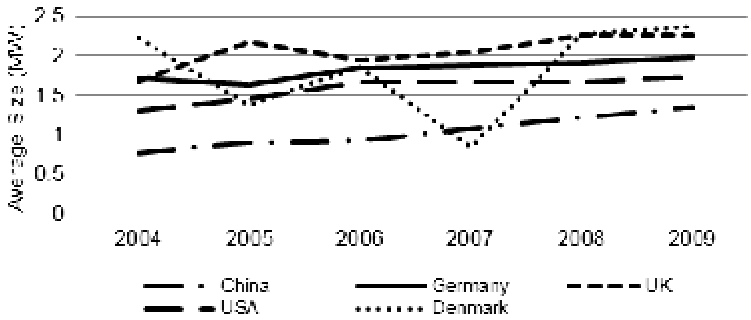
Wind turbines produced by neighbouring wind giants like China, which has the largest installed capacity of approximately 44 GW by 2010, and India, which has installed capacity of approximately 13 GW by 2010, now considered the world's 5th

largest, have an economical advantage over European competitors. An overview of the wind turbines produced in these countries is provided in this section.

Considering that the main wind turbine developers in Asia are operating under the license of more mature manufacturers from Germany and Denmark some overview of their wind turbine development together with UK and USA are also presented here.

Figure 10 shows the average size of wind turbines installed in some countries for comparison.

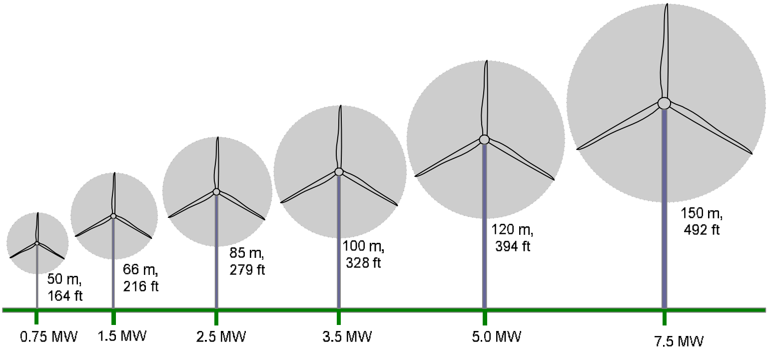
Figure 10 - Average Size of Wind Turbines in Some Countries Considered



Source: Indian Wind Energy Outlook, 2011.

In Europe wind energy technology has evolved rapidly over the last three decades (Figure 11) with increasing rotor diameters and the use of sophisticated power electronics to allow operation at variable rotor speed. Originally almost all wind turbines used in wind farms were Type A. In early 2000, Type C wind turbines emerged in many parts of Europe with a capacity of about 1 to 2 MW. Today Type C designs of capacities around 5 MW are available. Some manufactures are also offering geared and gearless Type D wind turbines. Table 6 summarizes the wind turbines offered by some major wind turbine manufacturers. With the maturity of offshore technology, very large wind turbines such as Vestas 8 MW, Siemens 6 MW and Enercon 7.5 MW emerged.

Figure 11 - Evolution of Wind Turbine Technologies



Source: Olimpo et al. Wind Energy Generation: Modelling and Control. 2009.

The main players in China include Sinovel Wind Power Technology Co., Ltd., Dongfang Turbine Co. Ltd., Xinjiang Goldwind Science & Technology Co. Ltd. and Guangdong Mingyang Wind Power Technology Co., Ltd. Even though it is not possible to gather exact technical information about the turbines produced by these companies, majority of them have variable speed turbines. Some manufacturers specify that they produce Type D gearless wind turbines.

Table 6 - Wind Turbines Offered by Some Manufacturers

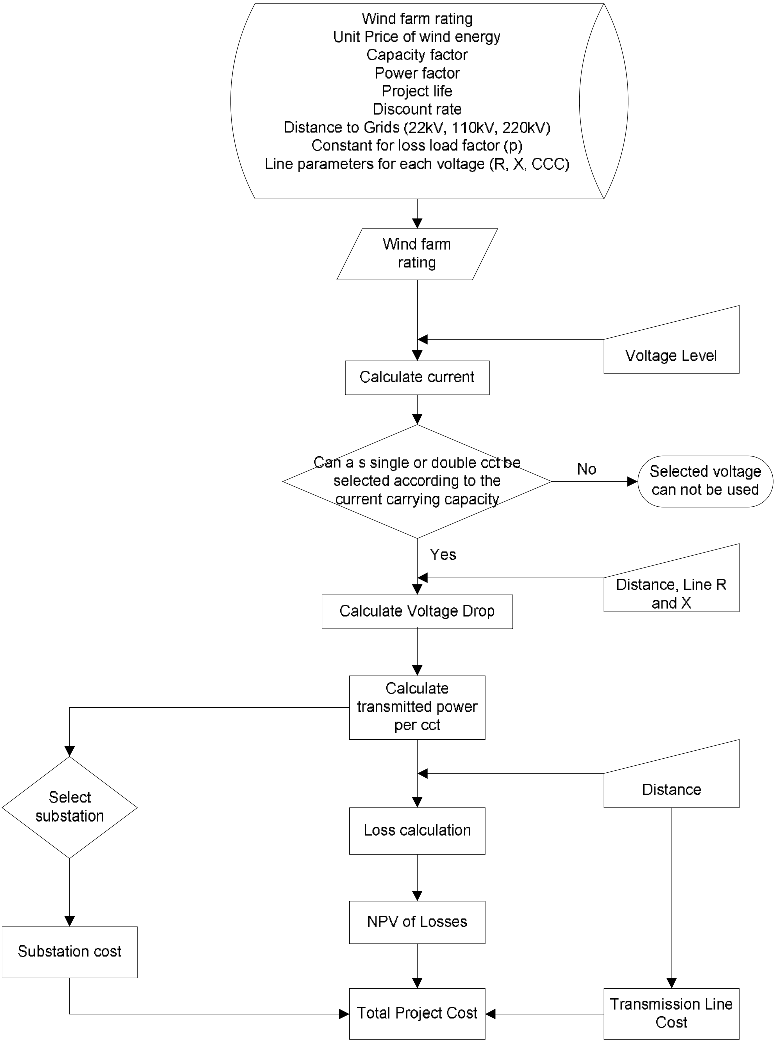
Manufacturer	Wind Turbine	Power Output (MW)	Power and Speed Control Technology
VESTAS (DK)	V90	3.0	Type C – Geared
	V112	3.0	Type D- Permanent Magnet – Gearless
	V164	8.0	
ENERCON (GE)	E82	3.0	Type D - Annular synchronous generator – Gearless
	E126	6.0	
GE WIND (US)	2.5-100	2.5	Type D - Permanent Magnet – Geared
	4.1-113	4.1	
SIEMENS (GE)	SWT 3.6 107	3.6	Type D – Induction Generator – Geared
	SWT 3.0 101	3.0	Type D - Permanent Magnet – Gearless
	SWT 6.0	6.0	

Source: Various Publications

In India, the main player is Suzlon Energy which produces about 4 to 5 GW of cumulative capacity of wind turbines per year. They produce Type A wind turbines of ratings 0.6, 1.25, 1.5 and 2.1 MW. Another key player based in South India is

RRB Energy which produces 600 kW Type A wind turbines and 1.8 MW Type D wind turbines. Enercon India has installed over 4100 wind turbines of a cumulative capacity of over 2900 MW. It produces Type D gearless wind turbines of rating 800 kW. RegenPowertech recently set up a 300 MW manufacturing facility in Andhra Pradesh and manufactures 1.5 MW Type D gearless wind turbines. Other players in India include Gamesa, GE Wind and Essar Wind, and they produce Type C wind turbines of different capacities.

Figure 12 - Procedure to Choose the Point of Connection


Wind farm rating
Unit Price of wind energy
Capacity factor
Power factor
Project life
Discount rate
Distance to Grids (22kV, 110kV, 220kV)
Constant for loss load factor (p)
Line parameters for each voltage (R, X, CCC)
Wind farm rating
Voltage Level
Calculate current
Can a s single or double cct be selected according to the current carrying capacity
No
Selected voltage can not be used
Yes
Distance, Line R and X
Calculate Voltage Drop
Calculate transmitted power per cct
Select substation
Distance
Loss calculation
NPV of Losses
Substation cost
Total Project Cost
Transmission Line Cost

3 TECHNICAL CRITERIA FOR WPGF CONNECTIONS

3.1 Wind Penetration

The technical criteria should be based on the scale of wind penetration into the Vietnam grid. Therefore, it is important to set an upper limit for wind penetration that sets the validity of the criteria outlined in this manual. By observing the wind penetration levels in Vietnam as earlier shown in Table 1, it can be concluded that *these wind connection criteria is only valid up to 5% of wind penetration with respect to system capacity*. If the wind penetration is beyond 5%, it is recommended to revisit the technical criteria set forth in this manual.

3.2 Demarcation in Terms of Connection Voltage

As shown in Figure 1, it was found that the majority of the proposed wind additions in Vietnam (especially in Binh Thuan province) up to the time horizon considered in this report will be less than 200 MW and they will be connected to the POC with a link less than 15 kilometers. From the economic analysis carried out in Section 2.2, it can be concluded that for this distance, small WPGF that are directly connected to 22 kV transformer, P1 could be taken as 19 MW and medium sized WPGF that are connected through a 110/22 kV transformer, P2 could be taken as 200 MW.

3.3 Connection Criteria

Based on the best international practices and considering the determinations made above, the following connection criteria would be adopted in Vietnam.

I. Wind farms connected to 110 kV or above shall follow transmission connection codes, whereas lower connections shall follow distributed generation (also called DG) connection codes.
II. Wind farms connected to 110 kV or above, and with capacity greater than 19 MW, shall follow transmission connection codes. Otherwise, the wind farm shall follow DG connection codes.

Table 7 - Connection Criteria – Summary

Criteria	Wind Farm Capacity	Voltage Level	Connection Code
I	Any	110kV or above	Transmission Code
		Below 110kV	DG Code
II	19MW and above	110kV or above	Transmission Code
	Below 19MW	Below 110kV	DG Code

3.4 Selection of the Appropriate Connection Code

Accordingly, the following steps shall be followed for the selection of the appropriate connection code for a specific WPGF:

1. From wind resource assessment, decide the capacity of the wind farm.
2. Based on an economic study as described in Section 2.2, decide which voltage level the wind farm should be connected to.
3. If the economically preferred voltage is less than 110 kV (i.e. 22 kV), refer to DG connection requirements. Otherwise, refer to transmission connection requirements.

4 WPGF CONNECTION REQUIREMENTS

4.1 Introduction

This section of the manual establishes the minimum technical criteria with respect to design, connection, performance, protection and telecommunication requirements that need to be followed by

i. TNO/DNOs at the existing connection sites
ii. TNO/DNOs when connecting to new WPGFs
iii. WPGFs when seeking connection to the grid or modifying existing connections

Establishment of such criteria will assure a safe, stable and secure grid, and will also ensure a transparent and non-discriminatory process for connection by all prospective WPGFs.

4.2 Procedure for Application for Grid Connection

4.2.1 Application by a WPGF

Any WPGF seeking a new connection or modification of the existing installation shall submit a formal application to the TNO/DNO along with the application fee, which covers the cost of preliminary evaluation, grid impact assessment studies (GIAS) and other administration costs.

Details that should be reported by the WPGF at various stages of the grid connection process are given in Appendix to Section 4, part 4.A.

4.2.2 Application Processing

TNO/DNOs shall establish application procedures for WPGFs seeking connection or modifications. Broadly, the program for processing the application shall include the following:

a. Preliminary evaluation
b. Grid impact assessment
c. Submission of the offer to the applicant
d. Applicant's acceptance of the offer
e. Entering into the agreement for detailed studies and further processing
f. Submission of information pursuant to the agreement entered into
g. Detailed evaluation of the application
h. Entering into connection agreement
i. Submission of information prior to commissioning tests
j. Commissioning tests

k. Commissioning and connection
l. Connection records maintenance

4.2.3 Grid Impact Assessment Studies (GIAS)

TNO/DNOs shall conduct grid impact assessment studies for all new applications/modifications. This study will mainly focus on the following:

a. Grid performance with the new connection
b. Protection system coordination
c. Suitability of the voltage level
d. Fault level implications
e. Impact on power quality

If the GIAS shows that any proposed connection/modification will result in the degradation of the grid's system performance as defined by standards established in Circular 12 for connections at or above 110kV or Circular 32 at connections below 110kV, the TNO/DNO shall inform the applicant accordingly, citing the reasons for rejection. Whenever possible, the TNO/DNO shall propose suitable alternative measures such as adopting a higher connection voltage level or incorporating suitable auxiliary equipment to eliminate or to mitigate potential adverse effects.

TNO/DNO shall exert best efforts to reach an agreement on the proposed development and if such an agreement cannot be reached, the application shall be rejected.

Also, the TNO/DNO may reject the application, if acceptance of said application will lead the TNO/DNO to be in breach of the laws, decrees, rules, license conditions, regulations or rules. In the event of such a rejection, TNO/DNO shall give the reasons for rejection quoting relevant statutes affected.

The applicant has the right to appeal to ERAV for redress, against the decisions of the TNO/DNOs.

4.2.4 Submission of the Offer

If the TNO/DNO is satisfied that the application for the new connection/modification is in compliance with the requirements stated above, the applicant shall be informed of the acceptance of the proposed development along with the following:

a. Indicative connection costs
b. Detailed studies TNO/DNO intends to carry out and corresponding costs
c. Proposed agreement for further processing of the application which shall include the following:

i. Provision of all data in accordance with Appendix 4.A. by the applicant and also any other relevant information requested by the TNO/DNO
ii. Provision of all necessary information by the TNO/DNO in accordance with the statutory obligations and as required by this manual
iii. Agreement on the operational boundary between TNO/DNO and the applicant
iv. Procedure and the period within which the applicant has to make all all necessary payments

In the event that TNO/DNO and the applicant cannot agree on any of the items referred to in (a) or (b) above, the applicant has the right to raise the matter to ERAV.

4.2.5 Detailed Evaluation of the Application

Upon the acceptance of the applicant's offer, as stated in steps 4.2.2 (c) and 4.2.2(d) above, the TNO/DNO shall carry out all studies necessary. The results of the studies may include the following:

a. The preferred locations and alternate locations where the facilities under the proposed development may be connected to the grid
b. Any modifications and/or additions needed by the grid (including earthing systems) to accommodate the proposed development
c. An estimate of costs for additions and modifications to the grid specified in b. above
d. The major connection equipment that should be furnished under the scope of the proposed development
e. Revenue metering and telemetry requirements
f. Communications requirements, operational control facilities and maintenance requirements
g. Approximate schedule and lead times for TNO/DNO to perform its design, materials procurement, construction and connection
h. Preliminary project requirements diagram that illustrates the above items

4.2.6 Commissioning and Connection

If all abovementioned matters have been agreed between the WPGF and the TNO/DNO, both parties enter into a connection agreement. If the WPGF complies with the conditions to the satisfaction of the TNO/DNO, then both parties proceed to the commissioning tests phase. In case of connection to a transmission network, commissioning tests shall include the following:

a. Testing of the voltage regulation system
b. Tests to demonstrate WPGF's ability to provide continuous active and reactive power as per requirements
c. Tests to show compliance with established power quality standards

4.2.6.1 Responsibilities and Witnessing of Commissioning Tests

WPGF will nominate a qualified person to act as their representative during the commissioning phase.

The TNO/DNO will nominate a qualified person to act as his representative to witness commissioning tests. This person will coordinate with the WPGF representative. Together they must reach an agreement on test procedures and equipment to be used for the testing.

It is the responsibility of the WPGF representative to coordinate meetings with the TNO/DNO, review and agree on test procedures and undertake commissioning tests. WPGF may use staff and equipment made available by the TNO/DNO, or an authorized third party, to assist in the tests.

Prior to testing, the WPGF representative will certify by signature that,

i. The WPGF's earthing system conforms to the provisions in this manual and other relevant standards
ii. The design and implementation of the WPGF complies with the requirements of this manual, as well as the protection requirements specified in the power purchase agreement, if any
iii. The WPGF is safe to operate and complies with all the relevant requirements specified in this manual and other relevant statutory requirements.
iv. The commissioning tests for the wind turbine generators (WTG) and its transformers have been completed, including all protection relays, current transformers (CTs) and voltage transformers (VTs).

On the successful completion of the commissioning tests, the TNO/DNO shall issue a Technical Completion Certificate (TCC) for the connection.

Physical connection to the grid shall be effected, within ten days from the issue of the TCC.

However, if the commissioning tests are not successful, the TNO/DNO may refuse to issue a TCC or issue a conditional TCC specifying the new tests or changes that the WPGF must carry out.

4.2.7 Connection Point Information

In addition to the records that are kept, both the TNO/DNO and the WPGF shall compile a Connection Point Document (CPD).

It shall include the following:

a. Single line diagram of the connection point
b. Equipment and their ownership at the connection point

c. Ratings of the equipment used at the connection point
d. Authorized officers for operation and safety
e. Operational procedures and the parties responsible for operation
f. Names of officers who prepared the CPD, the dates and their signatures

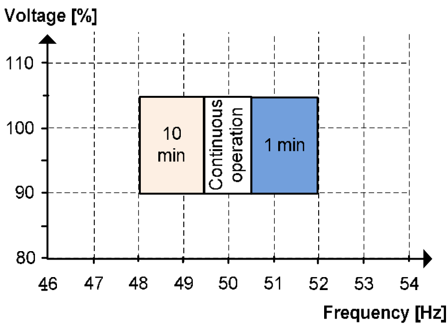
Whenever changes are made at the connection point, appropriate entries shall be made in the CPD, with the names and signatures of the officers who have done such changes and the dates on which such changes have been introduced.

4.3 WPGF Connection Requirements for Distribution Systems (Voltage Levels ≤ 35kV)

4.3.1 Operating Voltage and Frequency

WPGF shall be capable of continuous operation within the voltage range at the POC and frequency range as specified in Figure 13. Further, WPGF shall ensure that the facility will remain in operation for the specified time frames in accordance with Figure 13.

Figure 13 - Proposed voltage and frequency capabilities of wind generators



Voltage	Freq	Operation
90-105%	49.5 – 50.5Hz	Continuous
90-105%	48 - 49.5Hz	Capable of operating for 10 min
90-105%	50.5 – 52Hz	Capable of operating for 1 min

4.3.2 Active Power and Remote Control of Production

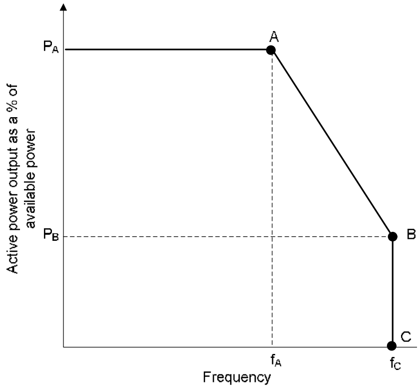
Considering the fact that primary response demands that turbines be deloaded, thus decreasing revenues, in the proposed DG connection codes, only curtailments will be considered.

The following are proposed:

- WPGFs with capacity greater than or equal to 5 MW should have capability to reduce power upon receiving a command from the TNO and its power output shall reduce the frequency as shown in Figure 14. This figure was derived from Irish and Indian grid codes. The value of P_A shall be 100% and P_B shall be 20 to 100%; whereas f_A shall be 50.5 to 51 Hz and f_C shall be 50.5 to 52 Hz. Further, f_A should be greater than f_{ace}.

- Small WPGFs with less than 5 MW capacity should have the capability to reduce power upon receiving a command from the TNO.

Figure 14 - Proposed Active Power-Frequency Capability Requirements

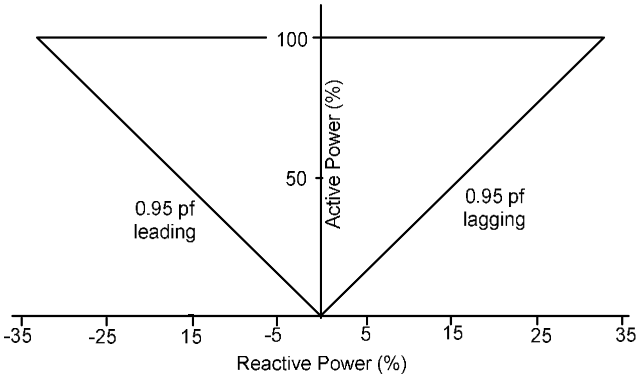


Frequency	f_A	50.5 - 51 Hz
	f_B	50.5 - 52 Hz
	f_C	50.5 - 52 Hz
Power		*Capacity ³5 MW*
	P_A	*100%*
	P_B	20-100%

4.3.3 Reactive Power

It is recommended that WPGF shall be capable of operating at any point within the power factor ranges illustrated in Figure 15.

Figure 15 - Reactive power capability requirements



Source: Recommended by Resource Management Associates

4.3.4 Operation under Fault Conditions

Considering the fact that LVRT capability is mainly included in countries where wind penetration is high or expected to be high in the foreseeable future, it is proposed to disconnect the wind farm during a grid fault if:

a. allowing a WPGF to remain connected to the grid under such fault conditions gives rise to hazardous situations such as:
   i. WPGFs absorbing large reactive currents, which have a negative impact on the grid
   ii. risk to maintenance personnel
   iii. out-of-phase reclosure due to islanded operation
   iv. unearthed islanded operation
b. a WPGF remaining connected further degrades grid performance with respect to:
   i. voltage levels
   ii. quality of power supply
c. a WPGF could suffer damages as a result of the grid fault
d. the cost of providing extra circuitry to equip WPGF with LVRT cannot be justified

4.3.5 Unbalanced Loading

A WPGF shall be capable of withstanding unbalanced loading and remain connected to the power system until the appropriate protection scheme clears the fault. Unbalanced loading capability of a WPGF shall be in accordance with Section 5 of Article 43 of the Circular 32.

4.3.6 Power Quality

The wind farm shall preserve the power quality and follow the flicker, voltage fluctuations and harmonic limits specified in Table 8.

Table 8 - Flicker, Voltage Fluctuations and Harmonic Limits

	Definition based on	**Limits based on**	**Limits**
Flicker	IEC 61000-4-15	Best international practices and IEC 61000-3-7	$P_{st95\%} = 0.40$ $P_{lt95\%} = 0.50$*
Voltage fluctuations	IEC 61400-21:2008	IEEE 519-1992	Voltage fluctuations due to switching operations< 3%
Harmonics	IEC 61400-21:2008 and IEEE 519-1992	IEEE 519-1992	For 69 kV or below: THD_V< 5% Individual voltage distortion < 3% For 69 kV above:

			THD_V< 2.5% Individual voltage distortion < 1.5%

** According to IEC 61000-3-7 (Limits — Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems) for systems of voltage levels < 35 kV indicative values of Pst = 0.9 and Pst = 0.7 and for systems of voltage levels > 35 kV indicative values of Pst = 0.8 and Pst = 0.6. However according to Danish distribution code flicker emission from the wind turbine should be less than 0.5 on 10-20 kV network and 0.35 on 50-60 kV network. According to German distribution codes long term flicker emission, Plt, at the connection point shall be less than or equal to 0.46.*

4.3.7 Grounding Arrangements

Neutral grounding of the DNO distribution systems vary. They may be isolated, Peterson coil or direct grounding depending on the voltage levels of the distribution systems, as per Article 10 of Circular 32.

To ensure that earth fault protection schemes of existing distribution systems are not disturbed, a WPGF shall be connected to such distribution systems through a transformer with a suitable vector group to:

a. Prevent distribution system earth faults appearing as earth faults on the WPGF side, and
b. Enable the total earth fault current to flow through the DNO’s distribution system neutrals.

4.3.8 Protection Schemes

All WPGFs are required to install protection schemes to:

a. protect the distribution system from faults originating in the WPGF, including but not limited to wind turbine generator, WTG step-up transformer, collector facilities and equipment used to interconnect the WPGF and the distribution system
b. protect the distribution system from the abnormal operating conditions of the WPGF
c. disconnect WPGFs during distribution system faults, and
d. disconnect WPGF when islanding occurs

All protection schemes of the WPGF shall be fully discriminative of the upstream DNO protection schemes.

4.3.9 Auto Reclosing

WPGF shall comply with Article 43 in Circular 32 which states that, “In case connection point has been equipped with automatic close equipment, the protection relay system of the power plant must be compatible with automatic close equipment of the DNO. Automatic close equipment are designed to separate the generator units from distribution network as soon as a circuit breaker is installed. An automatic close equipment or segment breaker opens at the start and maintains the separation from the distribution network until operation is resumed."

4.3.10 Repetitive Faults

Due to frequent occurrence of faults in sub-transmission network, wind turbines used must be capable of withstanding repetitive faults.

4.3.11 Surge Protection

Occurrence of transient over-voltages can be due to external as well as internal causes. Lightning is the most common source for transient over-voltages. Location of the arrestor, proper rating, connections to earth electrodes and the design of the earth system are critical factors that will maximize the arrestor effectiveness.

Surge protection for the WTG step-up transformer shall be in accordance with the DNO specifications, and this will ensure that it is coordinated with the interconnecting DNO equipment at BIL (basic insulation level).

4.3.12 Disconnection Facilities

WPGF shall provide necessary facilities to disconnect it from the distribution system at the POC. All equipment used for such interconnection facilities shall be in accordance with the DNO specifications.

4.3.13 Supervisory Control and Data Acquisition Requirements

To ensure reliable and secure operation of distribution networks, WPGFs are required to comply with the SCADA requirements as outlined in Circular 32, Clauses 40 and 41.

It is recommended that WPGFs exceeding 10MW shall provide information related to the wind speeds in addition to those specified in the preceding paragraph.

4.3.14 Communications

WPGF communications systems shall comply with the Article 40 of Circular 32.

4.3.15 Information Exchange and Performance Monitoring

4.3.15.1 Information Exchange

As required by the Circular 32, Article 84, WPGF and DNO shall reach a consensus on information exchange mode in accordance with the connection agreement.

4.3.15.2 Remote Monitoring Facility

If required by the DNO, WPGFs shall provide equipment necessary for remote monitoring of its operating conditions, which shall include the following:

- **i.** Generating unit output
- **ii.** Loading on switchgear
- **iii.** Protection relay operations
- **iv.** Alarms, indicators and event updates

4.3.15.3 Performance Monitoring Facility

Generating units shall have high resolution performance monitoring/recording facility that shall include the following features:

- i. transient and dynamic response of the generating unit in terms of real and reactive power output (MW and MVAr)
- ii. frequency (Hz) and collector bus voltages (Volt)
- iii. generator output currents as defined by the DNO

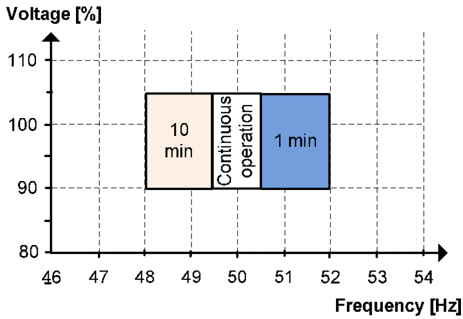
When requested by the DNO, WPGFs shall be required to make provisions to install a system disturbance recorder to record the system parameters. DNO shall have the right to decide on the specifications of such equipment.

4.4 Connection requirements for transmission network (Voltage levels ≥ 110 kV)

4.4.1 Operating Voltage and Frequency

WPGF shall be capable of continuous operation within the voltage range at the POC and frequency range as specified in Figure 16. Further, WPGF shall ensure that the facility will remain in operation for specified time frames in accordance with Figure 16.

Figure 16 - Voltage and Frequency Capabilities of Wind Generators



Voltage	Freq	Operation
90-105%	49.5 – 50.5Hz	Continuous
90-105%	48 – 49.5Hz	Capable of operating for 10 min
90-105%	50.5 – 52Hz	Capable of operating for 1 min

4.4.2 Active Power and Remote Control of Production

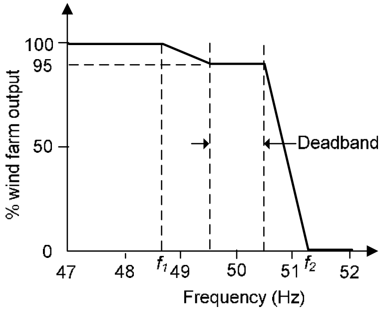
WPGF shall adhere to the following conditions:

a. All wind turbines shall provide primary and high frequency control during power system frequency excursions. A wind turbine's control equipment shall change the production depending on the grid frequency as shown in Figure 17. In order to provide primary response wind turbines shall be deloaded by 5% of its available output and maintain a deadband of 49.5 to 50.5 Hz for its continuous operation .

b. All wind turbines connected to the transmission voltages shall be fitted with a fast acting speed governing system to provide frequency response under normal operating conditions. The speed governor shall be capable of accepting and raising, lowering signals or set-points from SCADA/DMS system of the SO and electricity market, unless this requirement is waived by the SO and electricity market.

c. The speed governor of wind turbines shall be fitted with a governor capable of an overall governor speed droop characteristics of 5% or less.

Figure 17 - Active power output control for frequency support



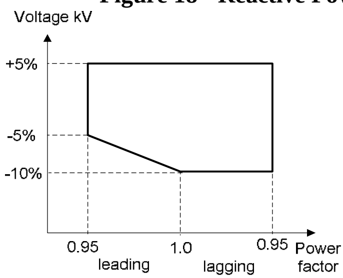
Frequency range	**Operation**
$f<f_1$ Hz*	100% output
$48.5<f<49.5$ Hz	95% to 100% output
$49.5<f<50.5$ Hz	Continuous operation at 95% output
$50.5<f<f_2$ Hz*	Power reduction

* f_1 and f_2 to be decided based on dynamic studies

4.4.3 Reactive power

The wind farm shall fulfil the range of reactive power requirements shown in Figure 18.

Figure 18 - Reactive Power Capability Requirements

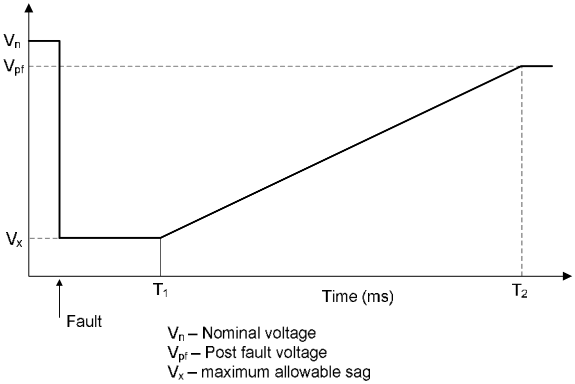


Operating region	**Recommended Criteria**
Power factor of 1.0 to 0.92 lagging and voltage of -10% to 5%	Wind farm should have capability to operate anywhere in this region
Power factor of 1.0 to 0.95 leading and voltage of -5% to 5%	Wind farm should have capability to operate anywhere in this region
Power factor of 1.0 to 0.95 leading and voltage of -10% to -5%	Wind farm should have capability to operate as specified by Figure 18

4.4.4 Operation Under Fault Conditions

In the absence of any dynamic studies, LVRT performance shown in Figure 19 is suggested. The exact shape shall be established by extensive dynamic studies as discussed in the Appendix to Section 4, part 4.B.

Figure 19 - Proposed LVRT Requirements



4.4.5 Unbalanced Loading

A WPGF shall be capable of withstanding unbalanced loading and remain connected to the power system until the appropriate protection scheme clears the fault. It is recommended that unbalanced loading capability of a WPGF shall be in accordance with Article 32(8)(a) and (c) of Circular 12, which states that each generator unit or generating station shall be capable of continuous uninterrupted operation with an unbalanced load up to 10% that may result in negative sequence currents not exceeding 5% of the rated capacities.

4.4.6 Power Quality

The wind farm shall preserve the power quality and follow the flicker, voltage fluctuations and harmonic limits specified in Table 9.

Table 9 - Flicker, Voltage Fluctuations and Harmonic Limits (Higher Voltage)

	Definition based on	Limits based on	Limits
Flicker	IEC 61000-4-15	IEC 61000-3-7 and best international practices	$P_{st95\%}$ = 0.60 $P_{lt95\%}$ = 0.50*
Voltage fluctuations	IEC 61400-21:2008	IEEE 519-1992	Voltage fluctuations due to switching operations < 3%
Harmonics	IEC 61400-21:2008 and IEEE 519-1992	IEEE 519-1992	For 69 kV < Voltage < 161 kV: THD_V< 2.5% \ndividual voltage distortion < 1.5% For Voltage > 161 kV: THD_V < 1.5% Individual voltage distortion < 1.0%

** According to UK grid codes for voltages above 132kV, short term flicker severity of 0.8 Unit and a long term flicker severity of 0.6 Unit are specified. According to German grid code long term flicker limitation is 0.37.*

4.4.7 Grounding Arrangements

EVN transmission network is operated as an effectively (solid) grounded system. WPGF shall ensure that the grounding of neutrals of the step-up transformer, from the collector bus to the transmission system, complies with Article 36 of Circular 12.

4.4.8 Protection Schemes

All WPGFs are required to install protection schemes to

a. protect the transmission network from faults originating in the WPGF, including but not limited to the wind turbine, generator, WTG step-up transformer, collector facilities and equipment used to interconnect the WPGF and the transmission network
b. protect the transmission network from the abnormal operating conditions of the WPGF
c. protect WPGF from the abnormal operating conditions of the transmission network and transmission network faults. In such instances, only the circuit breaker of the WPGF step-up transformer shall trip and cascade tripping is not permitted, except under breaker fail conditions, and
d. All protection schemes of the WPGF shall be fully discriminative with the upstream TNO protection schemes.

4.4.9 Surge Protection

Surge protection for the WTG step-up transformer shall be designed taking into account the average isokeraunic level (thunderstorm days per year) for the particular farm site. Location of the arrestor, proper rating, connections to earth electrodes and the design of the earth system are critical factors that will maximize the arrestor effectiveness.

Surge protection shall be coordinated with the interconnecting TNO equipment at BIL (basic insulation level).

4.4.10 Disconnection Facilities

WPGF shall provide necessary facilities to disconnect it from the transmission network at the POC. All equipment used for such interconnection facilities shall be in accordance with the TNO's specifications.

4.4.11 Supervisory Control and Data Acquisition Systems

To ensure reliable and secure operation of the distribution networks, WPGFs are required to comply with the SCADA requirements as outlined in Circular 12, Article 31. In addition, information from WPGFs related to voltage regulation system set point and wind speed shall be provided through SCADA.

The TNO and WPGF shall agree on the SCADA/DMS system requirements for each WPGF and define the same in the connection agreement, including the method of aggregation of information that SCADA will use to monitor multiple sites.

4.4.12 Communications

WPGF communications systems shall comply with Article 30 of Circular 12.

4.4.13 Information Exchange and Performance Monitoring

4.4.13.1 Information Exchange

As required by Article 84 of Circular 12, WPGF and DNO shall reach a consensus on information exchange mode in accordance with the connection agreement.

4.4.13.2 Remote Monitoring Facility

WPGFs shall provide equipment necessary for remote monitoring of its operating conditions, which shall include the following:

i. Generating unit output
ii. Loading on switchgear
iii. Protection relay operations
iv. Alarms, indicators and event updates

4.4.13.3 Performance Monitoring Facility

WPGFs shall have high resolution performance monitoring/recording facility that shall include the following features:

i. transient and dynamic response in terms of real and reactive power output (MW and MVar)
ii. frequency (Hz) and collector bus voltages (Volt), and
iii. generator output currents as defined by the DNO

WPGFs shall be required to make provisions to install a system disturbance recorder to record the system parameters. TNO shall have the right to decide on the specifications of such equipment.

APPENDIX TO SECTION 4

4.A. INFORMATION AND DATA

a. Information to be provided by a WPGF for preliminary evaluation

The following information must be submitted by a WPGF seeking a new connection or modification of the existing installation for purposes of preliminary evaluation

Information Description	Reference
Developer Details	4.2.1
Name of the proposed WPGF and location • Company name • Contact details – address, email, fax and telephone numbers • Company particulars – such as annual reports, company registration • Name, designation of the authorised signatory of the applicant company • Past experience with similar projects	
Project location	
• Village name • District/Province • Land area • Survey plan	
Project details	
• New connection or a modification • Total estimated cost • Proposed project commencement date • Scheduled commissioning date	
Technical details of the project	
• Total generation capacity (MW and MVA) • Type of WPGF (Type A, B, C or D) • Capacity of each generating unit (MW and MVA) • Connecting voltage 22 kV, 35 kV, 110kV, 220kV • Expected annual energy output of the proposed wind farm (GWh) • Total power required for auxiliaries • Single line diagram, which shall include the following: - Busbar arrangements - Electrical circuit configurations (overhead lines/underground cables, transformers) - Switchgear, current transformers, voltage transformers	

b. Information to be Provided by DNO/TNO to a WPGF Applicant

Information Description	Reference
WPGF Name	4.2.4, 5.2.1
Point of Connection (location)	
Maximum fault levels (for equipment selection and earthing design):	
Network design symmetrical fault level (kA or MVA)	

Peak asymmetrical fault level at half cycle (kA)	
3-phase symmetrical fault level at half cycle (MVA or kA)	
X/R ratio for 3 phase symmetrical fault	
1-phase to earth fault level (kA) (neglecting earth system resistances)	
X/R ratio for 1-phase to earth fault. (neglecting earth system resistances)	
Minimum fault levels:	
3-phase steady state symmetrical fault level (MVA or kA)	
X/R ratio for 3 phase symmetrical fault	
1-phase to earth fault level (kA) (Neglecting earth system resistances)	
X/R ratio for 1-phase to earth fault (neglecting earth system resistances)	
Upstream protection:	
Type of protection WPGF has to be coordinated	
Setting details of the relays	

Note: This information shall include the planned (or prospective) fault levels expected by the TNO/DNO ten (10) years from the time of connection application.

c. Information to be provided by a WPGF for detailed evaluation
   i. Step-up transformer – Collector Bus to the Transmission/Distribution system
   ii. Step-up transformer – Wind Turbine Generator

Information Description	Reference
Rated capacity MVA	4.2.4
Rated voltage - Primary (kV) - Secondary (kV)	
Nominal voltage ratio, primary/secondary	
Positive sequence impedance at - Maximum tap (%) - Minimum tap (%) - Nominal tap (%)	
Zero phase sequence impedance (%)	
Tap changer range + % - %	
Tap changer step size %	
Tap changer type on load / off load	
Earthing - Primary - Secondary	
Vector Group	
Magnetizing curve	

   iii. WTG Information

Information Description	Reference
General Information	
WTG manufacturer	
Model number	
Year/Date of manufacturing	
Technical Information	

A detailed simulation model of the wind turbine(s) to be used in PSS/E format	4.2.4
Rated capacity (MW)	
WTG type - (A,B, C, D)	
Inertia constant	
Stator reactance	
Magnetising reactance	
Rotor resistance (at rated running)	
Rotor reactance (at rated running)	
Generator rotor speed range (minimum and maximum speeds in RPM)	
Performance Data	
Fault current contribution - Either a measured fault current envelop or a simple model to be included in fault analysis	
Unbalanced loading - Negative phase sequence withstand	
Active power regulation - Ramp rate (% of rated output per minute)	
Frequency control - Frequency response (regulate the output above a certain defined frequency, say 50.2 Hz)	
Reactive power capability - Limits on lagging and leading power factors within which the rated output can be guaranteed. - P-Q capability curve	
Harmonics and flicker generated at the wind turbine terminals - Total harmonic distortion and individual harmonic percentages with respect to the fundamental	

4.B. LOW VOLTAGE RIDE-THROUGH REQUIREMENTS

During a fault on the power system, if a large number of Wind Turbine Generators (WTGs) are disconnected from the system there could be a frequency instability when the fault is cleared. In order to avoid this, many utilities are now demanding low voltage ride-through (LVRT) requirements. However, more stringent LVRT requirements demand complex electronic circuits and controllers in the WTG, that could possibly increase the cost of wind turbines.

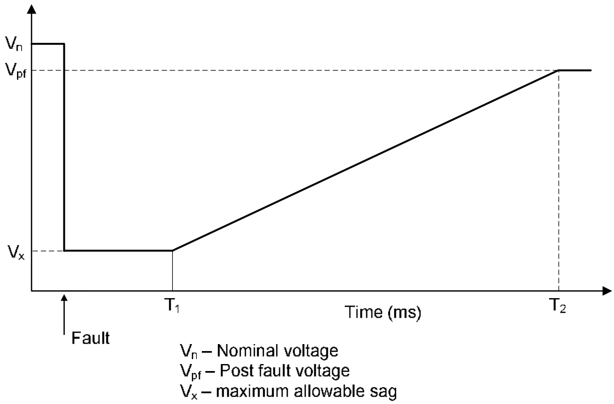
Therefore, it is important to assess the maximum allowable wind capacity that is allowed to be disconnected during a fault without hindering the stability of the system. A conservative approach is to consider this capacity to be equal to the largest generator on the power system.

Note that wind turbines which are exposed to wind speeds less than cut-in wind speeds are taken out of the system. Because the capacity of a wind farm varies with the wind conditions, extensive transient stability studies are required to establish the exact behavior of the system after recovering from a fault.

Also, it is worth noting that the addition of wind farms with Type C and D wind turbines reduces the overall inertia of the system, thus any mismatch of generation and demand after a fault is cleared results in higher excursions of frequency. Considering these, this appendix highlights the procedure for obtaining the optimum LVRT characteristics for the Vietnam power grid.

Proposed LVRT requirements in Figure 19 is repeated here in Figure 20 for easy reference.

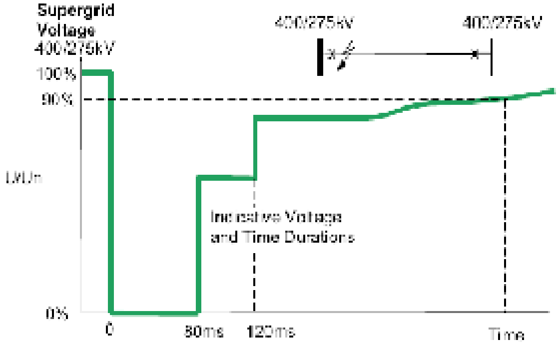
Figure 20 - Proposed LVRT Requirements (2)



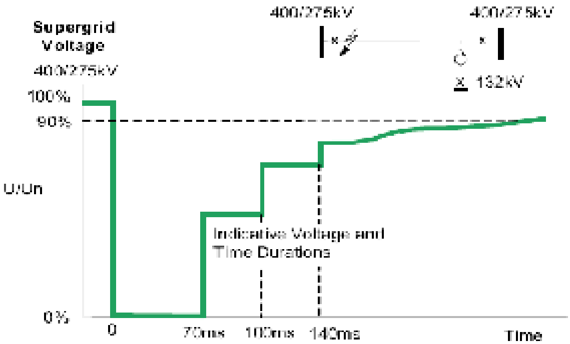
a. Determination of post fault voltage, V_{pf}

Figure 21 shows the typical fault recovery for cases with two and three-ended circuit breakers (see top right hand corner of each diagram for the configuration) extracted from the UK-Grid Code.

Figure 21 - Typical Fault Recovery for Two-ended and Three-ended circuits



Typical fault cleared in less than 140ms: 2 ended circuit 1`

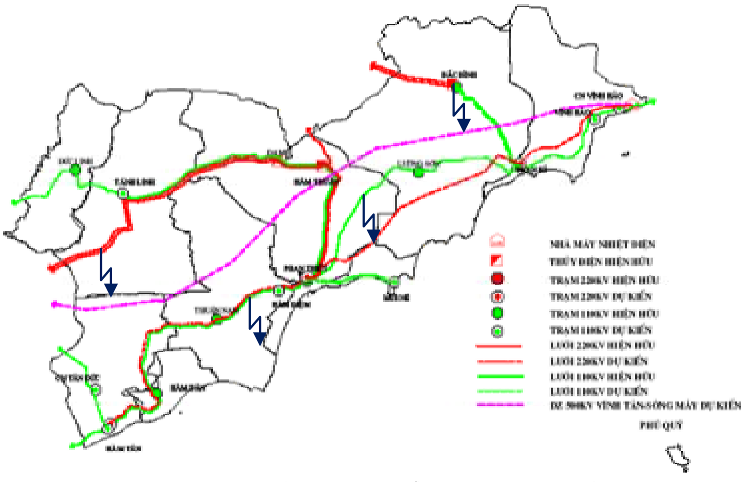


Typical fault cleared in 140 ms:- 3 ended circuit

Similar profiles need to be obtained for faults on different voltage networks to establish V_{pf}.

b. Determination of maximum allowable sag voltage, V_x
First step of establishing the maximum allowable sag voltage is to carry out vulnerability area studies (Dugan et al, 2004). As shown in Figure 22, apply faults at different locations of a network which is expected to have a large number of wind farms, and establish the voltage sag experienced by each wind farm.

Figure 22 - Typical Fault Recovery for Two-ended and Three-ended circuits



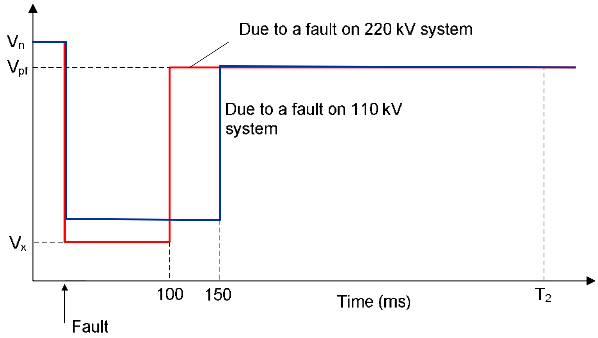
The vulnerability area studies require a large number of studies in key locations where there are wind farms of capacity approximately in the same order as the largest generator on the system.

The second step is an iterative process which first assumes a value for V_x. This value, together with vulnerability area studies, will reveal the wind farms that will not ride through the fault. This happens when sag voltage < V_x. Now carry out transient stability studies on the network under the same faults carried out in the first step, excluding the wind farms that will not ride through the fault. Depending on the outcome of these studies, either raise or lower V_x until an optimum is established.

c. Determination of time T_1

Time, $T_{1,}$ mainly depends on the fault clearance time on different voltage levels. When considering the fault clearance times given in Figure 23, one can see that a fault on the 220 kV network may introduce a sag on a wind farm connected to the 220 kV system for a maximum period of 100 ms. On the other hand, a fault on the 110 kV system may introduce a sag on the same wind farm connected to the 220 kV system for a maximum period of 150 ms. However, the severity of the fault is now less compared with a fault that is on the 220 kV system. This establishes the shape after T_1ms, shown in Figure 23. However, before establishing the exact characteristics, a large number of dynamic studies should be carried out in different parts of the power system.

Figure 23 - Effect of Protection on Fault Recovery



d. Determination of time T_2

Time, $T_{2,}$ mainly depends on the maximum fault clearance time and the voltage recovery time. According to Article 11 in Circular No. 12/2010/TT-BCT, the maximum fault clearing time is 150ms. However, the voltage recovery time can only be established by dynamic studies.

4.C. Definition of Harmonics and Flicker

According to IEEE 519-1992, Total Harmonic Voltage Distortion (THD_V) is defined as a percentage of the fundamental as:

$$THD_v = \frac{\sqrt{\sum_{h=2}^{50} V_h^2}}{V_1}$$

where V_1 is the fundamental voltage at the point of connection and V_h is the h^th harmonic component.

Flicker at the point of connection is defined as:

$$P_{st/lt} = \frac{1}{S_k}\sqrt{\sum_{i=1}^{N}\left[C_i \times S_{n,i}\right]^2}$$

where C_i is the flicker coefficient of the individual wind turbine

$S_{n,i}$ is the rated apparent power of the individual wind turbine

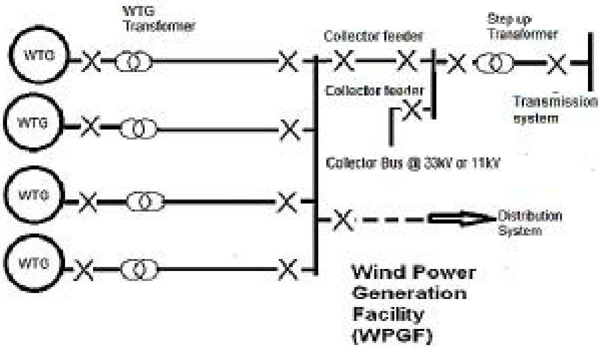
N is the number of wind turbines in a wind farm

S_k is the short circuit level at the point of connection

4.D. WPGF Protection

4.D.1 Introduction
A diagram of WPGFs connected to a transmission system and distribution system is shown in Figure 24.

Figure 24 - WPGF connected to the Distribution / Transmission system



Main components of a WPGF are a wind turbine generator (WTG), step-up transformer from generated voltage to medium voltage, collector feeders, collector bus and another step-up transformer from medium voltage to the transmission voltage level. The latter transformer will not be required if the WPGF will be connected directly to the distribution system.

Technical criteria for connection of WPGFs to distribution systems $\leq$ 35kV and transmission systems $\geq$ 110kV were defined in Section 4. The generator would be of Types A, B, C or D as explained in Appendix 2A.

4.D.2 Protection for WPGF

To design a protection scheme for a WPGF, it is imperative to be aware of the electrically hazardous conditions that may arise on each component of the WPGF, namely WTG, step-up transformers, collector feeders, collector bus and transmission line. Then the relays should be selected based on appropriate protection principles to detect the faults and isolate the faulty sections.

For the protection of WPGF the use of numerical relays equipped with IEC 61850 architecture is strongly recommended. They have advanced automated schemes features such as transfer trip and upstream blocking applications can be developed without the need of hard wire connections between devices and can thereby drastically reduce the overall costs of installation and maintenance.

4.D.3 Protection of Wind Turbine Generators

The WTG is basically an induction generator in the case of Types A, B and C, whereas in Type D it could be an induction generator or a permanent magnet synchronous generator.

Variety of faults can happen to the generator more than to any other item in the power plant's system and, as a result, its rotor or stator windings can get affected. These faults can be due to internal faults within the generator itself or imposed by the distribution/transmission system it is connected to.

Failure of stator insulation, power electronic controls and converter circuits are the main problems that arise due to machine faults, while abnormal running conditions such as overloading, over-voltage, overspeeding, phase and ground faults, unbalanced loading and islanding are imposed by the transmission/distribution systems to which the WPGFs are connected.

Protection relays that should be used to detect the above faults are listed below. However, the degree of protection will depend on factors such as the size of the generator and the purpose for which the WTG is used.

Protection function	**Faulty condition**
Restricted earth fault	Stator insulation failure
Inverse time voltage restrained or voltage controlled over current with high set elements	Generator faults, Back up for upstream phase faults
Instantaneous neutral over current	Back up for stator earth faults and earth faults within WTG protection zone
Negative sequence over current protection	Unbalanced loading
Negative sequence voltage protection	Unbalanced voltage
Generator under-voltage	Abnormal voltage condition
Generator over-voltage	-do-
Generator under-frequency	Abnormal frequency condition
Generator over-frequency	-do-
WTG pitch control	Overspeeding
Generator over-temperature using RTDs	Generator overloading
Crowbar protection	High rotor currents, which may subject the frequency converter of DFIG (Type C) to exceed its ratings.
Dynamic resistance	Transmission energy disruptions, over current in DC

4.D.4 Protection of WTG Transformer

WTG transformer steps up the voltage from the generated voltage to medium voltage. Depending on the rating of the transformer, protection relays/devices have to be selected.

Protection function	**Faulty condition**
Fuses on MV side using MV fuses	Transformer short circuits and back up for upstream/downstream faults
Over current earth fault relays if a breaker is used.	-do-
Differential protection (For large transformers > 1 MVA)	Transformer faults
Bucholz protection (For large transformers with conservators > 1 MVA)	Transformer winding faults (mainly inter turn faults)
Pressure relief valve (For sealed transformers)	-do-
LV side over current protection	Transformer faults

4.D.5 Protection of Collector Feeder

Collector feeders will become a part of an ungrounded system if the

a. particular distribution line to which the WPGF is connected gets disconnected from the relevant grid substation, in case of WPGFs feeding the distribution system; or
b. high voltage transformer between the collector bus and the transmission line trips, in case of WPGFs feeding the transmission system.

This may cause islanding, for which reason, anti-islanding relays become essential.

Protection function	**Faulty condition**
Over-current earth fault	Phase and ground faults
Under-voltage	Abnormal voltage conditions
Over-voltage	-do-
Under-frequency	Abnormal frequency conditions
Over-frequency	-do-
Rate of change frequency (ROCOF)	Anti-islanding
Vector shift	Anti-islanding
Neutral voltage displacement	MV earth faults under ungrounded system conditions.

4.D.6 Protection of Collector Bus

Protection function	Faulty condition
Bus differential	Bus faults
Breaker failure	Failure of a circuit breaker to operate
Backup over-current	Upstream/downstream faults

4.D.7 Protection of High Voltage Transformer

Protection schemes proposed underneath, except for breaker failure are absolutely essential, as there cannot be any compromise on transmission system protection.

Protection function	Faulty condition
Transformer differential	Transformer winding faults
Restricted earth fault	Earth fault on a transformer winding
Backup over-current	Upstream/downstream faults
Bucholz	Transformer winding faults mainly interturn faults
Standby earth fault	Back up for system earth faults
Breaker Failure	

4.D.8 Protection of Transmission Line

Protection schemes proposed underneath, except for breaker failure are absolutely essential, as there cannot be any compromise on transmission system protection.

Protection function	Faulty condition
Distance or differential (Main and secondary) with a transfer tripping scheme	Transmission line faults
Breaker failure	Failure of breakers
Backup over-current	Upstream faults not cleared by main protection

4.D.9 Protection of Capacitor Bank

Protection recommended here is not mandatory and may be selected based on the size of the capacitor bank to be protected.

Protection function	Faulty condition
Over current earth fault	Phase fault detection
Differential	-do-
Thermal overload	Exceeding the thermal current limits
Over-voltage	Abnormal operating conditions

5 TRANSMISSION AND DISTRIBUTION PLANNING FOR INTEGRATION OF WPGFS

5.1 Introduction

This section of the manual describes the design criteria and procedures to be followed by the TNO/DNOs in planning and developing their power systems in consideration of power generation from WPGFs.

This also specifies the information that existing and prospective WPGFs must provide to TNO/DNOs.

Main objectives of this part of the manual are to ensure that TNO/DNOs will:

a. plan, design and construct the transmission network and distribution networks to which WPGFs are connected or are expected to be connected, to operate in compliance with the requirements specified in Circulars 12 and 32, respectively
b. conform to the technical criteria and standards defined in this manual for acceptable performance at the interconnection between the transmission network / distribution networks and WPGF systems
c. facilitate the use of the transmission network and distribution networks by any WPGF connected or seeking connection to it, and
d. facilitate the exchange of information with WPGFs

5.2 Responsibilities

5.2.1 TNO/DNOs

TNO/DNOs shall be responsible for:

a. identifying the constraints of the transmission network/ distribution networks, with respect to transporting energy delivered by the WPGFs and proposing solutions with respect to voltage levels, loading of equipment, switchgear ratings, power quality, system loss, reliability and security of supply
b. planning the expansion of the transmission network / distribution network to take in energy generated by the WPGFs connected to their networks or new WPGFs that have received approval for connection
c. planning their networks to ensure that such networks will have the capability to meet the performance standards specified in Circulars 12 and 32, even after the integration of WPGFs
d. ensuring that the planned investment in the networks as stated in c. above is prudent, optimal and timely and that transmission or distribution asset utilization is at acceptable levels

e. reviewing and recommending the changes in planning standards on a periodical basis, and
f. providing all necessary system information to the WPGFs

5.2.2 Wind Power Generation Facilities

WPGFs shall be responsible for:

a. submitting all data that TNO/DNO will require for planning the transmission network/distribution networks,
b. keeping the TNO/DNO informed of retirement of any WPGFs, connected to the grid at least 12 months in advance, and
c. making submissions for improving the planning function.

5.3 Annual Transmission/Distribution Expansion Plans

As stated in Chapter IV of the Circular 12 and Circular 32, Annual Transmission Expansion Plan or Annual Distribution Plans have to be submitted for review and approval to ERAV not later than date…..month…year…. TNO/DNOs are also required to publish the plans immediately after the plan is approved by ERAV.

5.4 Data

A prerequisite for effective planning and design is data. Accordingly, TNO/DNOs and WPGFs shall provide all necessary data to either party.

For planning purposes, WPGFs already connected to the grid and WPGFs seeking connection to the transmission network/distribution network shall be required to furnish information and data to the TNO/DNO as specified in Appendix 5.A., in addition to data specified in Appendix 4.A.

General system data, single line diagrams, grounding arrangements, equipment ratings, fault levels, maximum allowable fault clearing times, loading levels of grid substations, primary substations, transmission lines, distribution lines and future development plans related to the transmission network / distribution network will be made available in their annual expansion plans.

The TNO/DNO, in turn, shall provide WPGFs seeking connections, site specific data such as geographical map showing the existing lines of the transmission network / distribution network and the proposed lines in the area where WPGF plans to undertake a development project.

5.4.1 Clarifications and Levying of Charges

If a WPGF seeks clarification on any data provided to them, the TNO shall provide him with all necessary information.

The TNO/DNO shall be entitled to charge reasonable fees to the WPGF requesting for any transmission/distribution network data. After receipt of specific request from the WPGF, the TNO/DNO shall estimate costs and time needed to retrieve the data requested and notify the WPGF of such costs.

After payment of the agreed price by the WPGF, the transmission network/distribution network shall be allowed a reasonable length of time for data collection depending on the nature and complexity of the data required.

5.4.2 Right to Withhold Information

The TNO/DNO shall be entitled to withhold any information related to the transmission network / distribution network if, with justifiable reasons, it deems that the disclosure of such information would seriously affect and compromise its commercial interests. However, the TNO/DNO shall not withhold the minimum data required by the WPGF to carry out its business.

5.4.3 Confidentiality of Data

All data supplied by the TNO/DNO to any WPGF or vice versa shall be treated as confidential and should not be divulged to any third party. The data shall be used only for the purpose for which it is furnished.

5.5 Technical Criteria for Planning

Technical criteria will be dependent on the amount of wind penetration into the power system. If and when the wind penetration level exceeds the set limits, technical criteria set forth in this manual have to be revisited and amended as necessary following the planning criteria in Table 11.

5.5.1 WPGF Capacities and Connection Voltages

As explained in Sections 2 and 3, connection voltages for the WPGFs based on their capacities and distance from the POC are given in the Table 10.

Table 10 - Voltage Levels / Circuit Types for Connection of WPGF

WPGF Capacity (MW)	Maximum Allowable Voltage Drop	Distance to the POC from WPGF (km)	Voltage Level and the Circuit Type
≤10	5%	≤14	22kV Single circuit 185 mm^2
≤10	5%	>14	22kV Double circuit 185 mm^2
>10 and ≤19	5%	≤15	22kV Double circuit 185 mm^2

>10 and ≤19	5%	>15	110kV Single circuit 240 mm^2
>19 and ≤100	5%	≤48	110kV single circuit 240 mm^2
>19 and ≤100	5%	>48	110kV double circuit 240 mm^2
>100 and ≤200	5%	≤48	220kV double circuit 400 mm^2

5.5.2 Wind Penetration

As explained in Section 2, projected wind penetration levels for the period 2011 to 2020, will be less than 5% of the minimum demand of the power system.

Even though results of a dynamic study on wind integration to the power system are not available, with the wind penetration levels expected to remain below 5% of the system maximum demand as well as the system minimum demand, it can be safely concluded that the WPGFs planned to be integrated during this period up to 2020, will not cause serious impacts on the stable operation of the power system.

Table 11 - Planning Criteria for Transmission Networks and Distribution Networks

	Transmission Network	Distribution Network
5.5.3 Network Capability	Transmission network shall be capable of taking delivery of all power generated by the WPGFs connected to their networks while ensuring that system performance will remain in compliance with the power system performance standards specified in Circular 12, Article 4-9, Chapter II, and Circular 32.	Distribution network shall be capable of taking delivery of all power generated by the WPGFs connected to their networks whilst ensuring that system performance will remain in compliance with the power system performance standards specified in Circular 12, Article 4-9, Chapter II and Circular 32[i].
5.5.4 System Reliability	Transmission networks that are to be used for connecting the grid substations and the WPGFs shall be designed for a reliability level of (N-1).	(N-1) reliability level cannot be recommended for distribution networks to which WPGFs are or to be connected.
5.5.5 Reactive Power Compensation and Voltage Regulation	Dynamic reactive power compensation by the WPGFs is recommended as only Type C and Type D will be connected to the Transmission systems. WPGF shall fulfil the range of reactive power requirements shown in Figure 18, Section 4.4.3 through a continuously acting voltage regulatory system.	In order to encourage small-scale wind farm developers, reactive power requirements will be limited to local power factor correction[ii].
5.5.6 System Security	It has to be ensured that transmission network security can be maintained[iii] with the integration of the WPGFs, in the event of system faults.	It has to be ensured that distribution network security can be maintained[iv] with the integration of the WPGFs, in the event of system faults.
5.5.7 Equipment Ratings	TNO shall ensure that system fault levels will remain within the design levels and no underrated switchgear is in service.	DNO shall ensure that system fault levels will remain within the design levels and no underrated switchgear is in service.

5.5.8 Protection Systems	WPGF protection systems shall be capable of (a) clearing all electrical faults originated within the WPGF systems discriminatively with the transmission (upstream) protection systems within acceptable time durations, (b) protect the transmission system from the abnormal operating conditions of the WPGF, and (c) protect the WPGF from the abnormal operating conditions of the grid.	WPGF protection systems shall be capable of (a) clearing all electrical faults originated within the WPGF systems discriminatively with the distribution (upstream) protection systems within acceptable time durations, (b) protect the distribution system from the abnormal operating conditions of the WPGF, and (c) disconnect WPGFs during grid faults, as such grid faults could give rise to islanded operation, which can cause hazards situations[v].

[i] *Considering the very low wind penetration levels, measures such as LVRT is not recommended, but providing fault current during a fault and continuing to generate as normally as possible after the fault is cleared, are always advantageous. Under the circumstances, it is recommended to encourage the incorporation of such measures by offering financial benefits.*

[ii] *This will reduce undue costs on small wind turbine developers thus encouraging them to develop more small scale wind farms.*

[iii] *Chapter VI-Circular 12*

[iv] *Chapter VI-Circular 32*

[v] *Unearthed operation of the distribution system, out of synchronization reclose, unacceptable quality of supply, risk to maintenance personnel.*

5.6 System Studies

The TNO/DNO shall carry out the following system studies to ascertain that the system meets the criteria described above such as:

a. Load flow studies
b. Contingency studies
c. Short circuit studies
d. Voltage stability studies
e. Protection system studies
f. Power quality studies

In addition to the above, the TNO shall carry out the following studies as well:

g. Transient stability studies
h. Steady state stability studies

APPENDIX TO SECTION 5

Information to be provided by a WPGF for System Planning Studies

(i) Step-up transformer - Collector Bus to the Transmission/Distribution system

(ii) Step-up transformer – Wind Turbine Generator

Information Description	Reference
Rated capacity MVA	5.4
Rated voltage - Primary (kV) - Secondary (kV)	
Nominal voltage ratio, primary/secondary	
Positive sequence impedance at - Maximum tap (%) - Minimum tap (%) - Nominal tap (%)	
Zero phase sequence impedance (%)	
Tap changer range + % - %	
Tap changer step size %	
Tap changer type on load / off load	
Earthing - Primary - Secondary	
Vector Group	
Magnetizing curve	

(iii) WTG Information

Information Description	Reference
General Information - WTG manufacturer - Model number - Year/Date of manufacturing	
Technical Information	
- A detailed simulation model of the wind turbine(s) to be used in PSS/E format	
- Single line diagram, which shall include the following: o Busbar arrangements o Electrical circuit configurations (overhead lines/underground cables, transformers) o Switchgear, current transformers, voltage Transformers	
- Rated capacity (MW)	
- WTG type - (A,B, C, D)	
- Inertia constant	

- Stator reactance	
- Magnetising reactance	
- Rotor resistance (at rated running)	
- Rotor reactance (at rated running)	
- Generator rotor speed range (minimum and maximum speeds in rpm)	
Performance Data	
Unbalanced loading - Negative phase sequence withstand	
Active power regulation - Ramp rate (% of rated output per minute)	
Frequency control - Frequency response (regulate the output above a certain defined frequency, say 50.2 Hz)	
Reactive power capability - Limits on lagging and leading power factors within which the rated output can be guaranteed - P-Q capability curve	
Harmonics and flicker generated at the wind turbine terminals - Total harmonic distortion and individual harmonic percentages with respect to the fundamental	

6 REVENUE METERING REQUIREMENTS

6.1 Revenue Metering Requirements for Distribution Network (Voltage Levels≤ 35kV)

Revenue metering of WPGFs shall be in accordance with the Chapter VII, entitled "Metering", in Circular 12, subject to the following changes:

Article 103.1(a) specifies that the meter shall be of three-phase, four-wire type. This shall be amended to read as "Meter shall be three-phase, three-wire type"

6.2 Revenue Metering Requirements for Transmission Network (Voltage Levels≥ 110kV)

Revenue metering of WPGFs shall be in accordance with the Chapter IX, likewise entitled "Metering", in Circular 12, subject to following changes:

Article 105.1(a) specifies that the meter shall be of three-phase, four-wire type.

This shall be amended to read as "Meter shall be three-phase, three-wire type"

Article 105.2(a) specifies that:

> "2. Accuracy class requirements:
>
> a) Main meters must have Accuracy class 0.5 for active energy metering, comply with the requirement of IEC 62053-22 standard; and 2.0 for reactive energy metering, comply with the requirement of IEC 62053-23 standard; and,"

This shall be amended as:

> a) Main meters must have Accuracy class 0.2 for active energy metering, comply with the requirement of IEC 62053-22 standard; and 2.0 for reactive energy metering, comply with the requirement of IEC 62053-23 standard; and

7 OFF-GRID SYSTEMS

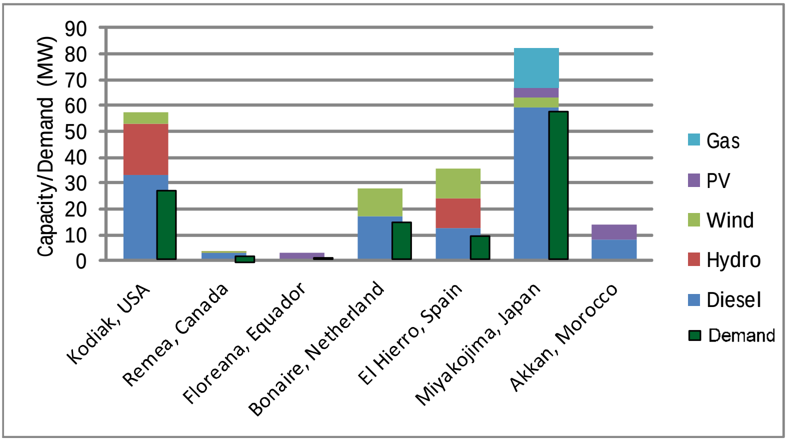
For off-grid power systems, conventionally, diesel generators were used. However, recently, hybrid systems that integrate wind, photovoltaic (PV) and battery energy storage may be considered. In this section, lessons learned from some of the existing systems, and standards that govern the selection and design of off-grid system components and procedures for system sizing are provided.

7.1 Lessons Learned from Existing Systems

This section summarizes selected existing off-grid projects from different countries. The lessons learned from these projects are:

1. In many existing projects, the available diesel generation capacity is always greater than the peak demand. Figure 25 shows the combination of different sources for some off-grid systems that currently exist. Peak demand is shown in dark green.

Figure 25 - Generation Capacity and Demand of Some Existing Installations



2. In islanded systems, the operating cost of diesel generation may be higher than that of renewables due to freight and fuel cost. For example in Kodiak Island, the wind electricity is estimated to cost US$0.12/kWh while the diesel power cost estimate is US$0.2538/kWh and rising.

3. When designing a hybrid system, it is important to maintain about 30% fuel load level on the diesel generators. The reason for this is to maintain adequately

high temperature in the chamber to foster efficient combustion. Otherwise, soot tends to build up, and may create problems in the system's performance.

4. It is more convenient if equipment providers and installers are locally available. Renewable energy projects that utilize local equipment and installers could create a number of jobs for local citizens and residents.

5. Limiting demand for energy is one of the approaches used to save power from off-grid systems. However, suitable incentives should be in place to increase energy supply so citizens can get the maximum benefit out of this service.

6. Community support in the form of contributions in-kind and contributions to the investment costs is important for the success of an off-grid project. Further, local community education and technical skills capacity building are also important.

7. The demand growth could be limited by considering more demand-side efficiency upgrades.

8. When introducing renewable energy projects, it is important to reap other benefits from the project. For example, in Miyakojima, Japan a number of the renewable projects were installed along a road which hosts the annual All Japan Triathlon Miyakojima race. This has helped promote tourism that can contribute to the local economy.

9. When designing off-grid projects it is important to forecast future electrical demand as it could grow very quickly.

7.2 Standards Relevant to Off-grid Projects

1. IEC 62257-1:2003: Contains recommendations for small renewable energy and hybrid systems for rural electrification specifically Part 1: General introduction to rural electrification.

2. IEC 62257-8-1:2007: Contains recommendations for small renewable energy and hybrid systems for rural electrification specifically Part 8-1: Selection of batteries and battery management systems for stand-alone electrification systems - Specific case of automotive flooded lead-acid batteries available in developing countries.

3. IEC 62257-7-3:2008: Contains recommendations for small renewable energy and hybrid systems for rural electrification specifically Part 7-3: Generator set - Selection of generator sets for rural electrification systems.

4. IEC 62257-3:2004: Contains recommendations for small renewable energy and hybrid systems for rural electrification specifically Part 3: Project development and management.

5. IEC 61427: This standard is about secondary cells and batteries for renewable energy storage, general requirements and methods of test. This IEC specifies the particular operating conditions experienced by secondary batteries in photovoltaic applications during their use.

6. IEC 62124: This standard is about photovoltaic (PV) stand-alone systems and design verification. This standard verifies system design and performance of stand-alone PV systems.

7.3 Sizing of Off-grid Generating Sources

The selection of best generation option depends on resource availability. Therefore, the first step in designing a hybrid system is a meteorological study, forming the base for selecting the preferred power source. In order to establish demand, it is important to analyse the local conditions and the community's needs. Once the demand and available resources are assessed, it is easy to use software, such as Homer, to optimize power generation depending on the different combination of generation and demand.

The following hybrid systems could be considered for off-grid applications:

7.3.1 Diesel Plus Renewables (Mainly Solar or Wind)

When designing a diesel plus renewable hybrid system, it is important to obtain an optimum capacity that minimizes the overall cost. The following costs are involved as recommended by IEC 62257-4:2005 (Recommendations for small renewable energy and hybrid systems for rural electrification - Part 4: System selection and design):

(a) Capital cost of each component
(b) Replacement cost of each component
(c) Operation and maintenance cost of each component

The capital cost of a system having N number of Diesel power plants and M number of renewable energy plant is given by:

$$C_{Capital} = \sum_{i=1}^{N+M} C_i^{(C)} \quad (1)$$

where $C_i^{(C)}$ is the capital cost of i^th power plant,

The operating cost is given by:

$$C_{Operating} = \sum_{t=1}^{T}\sum_{i=1}^{N} C_i^{(O)}(P_i^t) + \sum_{t=1}^{T}\sum_{i=1}^{M} C_i^{(O)}(R_i^t) \quad (2)$$

where $C_i^{(O)}$ is the operating costs of diesel generator i at time t or renewable generator i at time t,

P_i^t is the generating capacity of generator i at time t, and

R_i^t is the renewable generating capacity i at time t

A cost function $C_i^{(O)}$ contains fixed cost and variable operating costs as well as fuel input costs. The variable operating costs include all variable costs apart from fuel costs and are directly proportional to the power output of each generator. The fuel costs are determined by the fuel price, the power output and the heat rate of each generator.

For sizing the plant, the capital cost or capital plus operating cost over the life span of the project can be optimized. One way of expressing the objective function is:

$$F = C_{Capital} + \left[C_{Operating} - C_r\right]\left[\frac{1}{(1+r)^n}\right] \quad (3)$$

where r is the interest rate

n is the life time of the project

C_r is the revenue received through electricity sales

F is the objective function

If the capital cost of the project is spread out through financing of the equipment using loans over the life of the project, then the objective function is given by:

$$F = \left[C_{Capital} + C_{Operating} - C_r\right]\left[\frac{1}{(1+r)^n}\right] \quad (4)$$

Then the objective function (defined by equation 3 or 4) should be optimized under the following system constraints:

i. Power Balance Constraints.

At each time t forecast system demand L^t_{FC} minus forecast renewables output R_i^t must equal total diesel power generation:

$$\sum_{i=1}^{N} P_i^t = L_{FC}^t - \sum_{i=1}^{M} R_i^t \, . \qquad (5)$$

ii. Generation Constraints.

At each time step t generators and renewable energy sources are required to operate within their physical limits:

$$P_{i,\min} \le P_i^t , \qquad P_i^t \le P_{i,\max} , \quad 1 \le i \le N \, . \qquad (6)$$

$$R_{i,\min} \le R_i^t , \qquad R_i^t \le R_{i,\max} , \quad 1 \le i \le M \, . \qquad (7)$$

Objective function given in equation (4) shall be changed if ancillary services such as spinning reserve and reactive power requirements are included. The corresponding cost for obtaining ancillary services ($C_{ancilary}$) should then be included into equation (4) as:

$$F = \left[C_{Capital} + C_{Operating} + C_{ancilary} - C_r \right] \left[\frac{1}{(1+r)^n} \right] \qquad (8)$$

Further power balance equation need to be modified as:

$$\sum_{i=1}^{N} P_i^t + P_{spinning}^t = L_{FC}^t - \sum_{i=1}^{M} R_i^t \qquad (9)$$

where $P_{spinning}^t$ is the required spinning reserve at a given time t.

There may also be reactive power constraints.

7.3.2 Renewables (Mainly Solar or Wind) Plus Battery Energy Storage

In such systems reliability indices are used to decide optimum size of renewable energy plant. *ELF* is the ratio of effective load outage hours to the total number of hours. If $Q(h)$ is the amount of load that is not supplied at time step *h*, $D(h)$ is the demand power in h^{th} step, and H is the number of time steps; *ELF* is defined as:

$$ELF = \frac{1}{H}\sum_{h=1}^{H}\frac{Q(h)}{D(h)}$$

For off-grid projects $ELF \leq 0.01$ is acceptable. (Tina, Gagliano & Raiti, 2006)

When considering hybrid renewable energy system with battery energy storage, the procedure described in Section 7.3.1 is still applicable except equation (3) or (4) should include the cost of battery energy storage system and their replacement cost (as batteries may need to be replaced more than once during a life time of the project). Further $ELF \leq 0.01$ should be incorporated with the power balance constrained given in equation (5).

More detailed treatment of the sizing different component for rural electrification projects could be found in IEC 62257-4:2005. This standard could be adopted for off-grid projects as many rural electrification projects are off-grid or have a weak link to the grid.

APPENDIX TO SECTION 7

Facts about Selected Off-grid Power Systems

Island	Background information	Climate	Economic Activities
Kodiak Island, USA	Kodiak is the second largest island in the USA and is located about 400km southwest of Anchorage, Alaska.	Precipitation - heavy thought the year. Temperature • 4°C to 20°C in summer • -4°C in winter.	Fishing and tourism
Ramea Island, Canada	Ramea is a small remote island located off the southern coast of Newfoundland in Canada. It has a population of approximately 631 inhabitants, with 354 electricity customers.	Precipitation-moderate thought the year. The temperature averages 15°C, while averages in the winter months of January and February are around -4°C.	Fishing and tourism
Faroe Islands, Denmark	The Faroe Islands are a group of 18 islands in the North Atlantic Ocean. There are two main grids in the islands. There are also five smaller islands that are not interconnected.	Summer warmest average temperature not exceeding 10°C and coldest month at no lower averages of 0°C during winters	Fishing, tourism, oil
Isle Of Eigg, Scotland	The Isle of Eigg is part of the Small Isles Archipelago off the coast of Scotland. Households used their own diesel gensets plus a small hydroelectric generator that served several households.	Temperate climate, cool summers and mild winters.	Primarily tourism, fishing, farming, and construction
Floreana Island, Ecuador	Floreana is the smallest island of the Galapagos Archipelago, East Pacific.	The region has two major seasons. The dry season runs from July to December, and the hot or wet season lasts from January to June. The temperature averages 21°-30°C with annual average rainfall of 60-100mm.	Fishing, agriculture and tourism

Source: IEA-RTD, Renewable Energies for Remote Areas and Islands, 2012.

Island	Electrical Generation - Capacity
Kodiak Island, USA	• Wind: 3 x 1.5 MW GE SLE turbines • Hydro: 2 x 10MW hydro turbines at Terror Lake • Diesel: 1 x 7MW combined cycle and 26MW of reciprocating diesel generator.
Ramea Island, Canada	• Diesel: 3 x 925kW • Wind: 6 x 65kW and 3 x 100kW • Hydro: 1 x 250kW.
Faroe Islands, Denmark	• Diesel: 53.4 MW • Hydro: 31.4 MW • Wind: 1x150 kW, 6x660 kW, 1x220 kW • Solar thermal and wind/hydrogen installation to deliver heat and electricity
Isle Of Eigg, Scotland	• Run-of-river hydro: 1 X 100kW and 2 x 6kW • Wind: 4 x 6 kW • Diesel: 2 x 80 kW • PV: 30kWp • Energy storage: 48V battery with 4400Ah capacity
Floreana Island, Ecuador	• PV: 21kWp and 2 x 800Wp, • Solar Home Systems: 3 x 400 Wp • Batteries: total of 300Ah • Biodiesel gensets: 68kW each

Source: IEA-RTD, Renewable Energies for Remote Areas and Islands, 2012.

Island	Lessons Learned - Technical
Kodiak Island, USA	Kodiak island is expecting to increase generation from renewables to 98% (presently 92.9%).
Ramea Island, Canada	The addition of wind capacity provides benefits from surplus generation and reserve capacity. However excess capacity creates tensions between renewables generator and diesel operator which has to maintain a 30% capacity factor on the diesel generators.
Faroe Islands, Denmark	Storage of wind excess electricity in low electricity consumption can be used for other purposes (e.g. hydrogen-powered ferries or vehicles)
Isle Of Eigg, Scotland	One of its hydro turbine manufacturers was Australian, which complicated access to replacement parts. Therefore equipment providers and installers are more convenient when locally provided. If users exceed their allowed power demand limit, they are disconnected and charged a £25 reconnection fee. However, as a precaution, they are provided an alarm when they are about to reach the limit to help them adjust their usage.
Floreana Island, Ecuador	The meters supported demand limiting, but this functionality was later not used. The tariff structure did not provide incentives to limit electrical usage. The lack of an automatic start-up of the diesel genset causes interruptions especially at night when the utility operator is not present.

Source: IEA-RTD, Renewable Energies for Remote Areas and Islands, 2012.

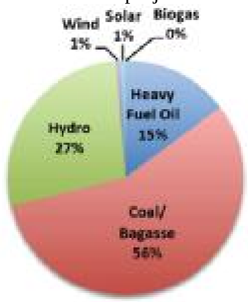
Island	Lessons Learned - Socio-economic
Kodiak Island, USA	On Kodiak, the wind electricity is estimated to cost US$0.12/kWh while the diesel power cost estimate is US$0.2538/kWh and rising.
Ramea Island, Canada	Nalcor engineers who put up the wind turbines have suggested that the project would not have been possible without the cooperation and engagement of the local community.
Faroe Islands, Denmark	Wind farms were built to address heating as it is the primary driver of energy demand.
Isle Of Eigg, Scotland	The community was highly involved and was the project promoter. Voluntary support was a valuable contribution to reduce system costs. For example, residents volunteered to lay cable and shared knowledge of the terrain with installers.
Floreana Island, Ecuador	One of the farmhouses uses a high-efficiency egg incubator for chickens. The PV facility was integrated onto a multi-use building built.

Island	Lesson Learned – Financial
Kodiak Island, USA	Government subsidies may be necessary to help smaller utilities deal with the large upfront capital costs inherent in most renewable energy projects.
Ramea Island, Canada	Fuel cost savings were less than initially projected.
Faroe Islands, Denmark	
Isle Of Eigg, Scotland	The community was reluctant to begin the project since they faced the high risk of paying for the initial design of the system before making investment. The search for funding was challenging.
Floreana Island, Ecuador	The community in Floreana contributed to the project both through contributions in-kind and a small percentage of the investment costs.

Source: IEA-RTD, Renewable Energies for Remote Areas and Islands, 2012.

Island	Background information	Climate	Economic Activities
Bonaire, Netherlands	Bonaire is a Caribbean island which has an area of almost 300km^2	The weather in Bonaire is tropical. Bonaire receives little rainfall, about 50 cm each year.	Tourism
El Hierro, Canary Islands, Spain	El Hierro Island is the smallest of the Canary Islands Archipelago.	The climate is warm and has a rainy season from November to March. Temperatures oscillate between 19 – 23 °C.	Public and private sector services, tourism and other commercial activities
Miyakojima, Japan	Miyakojima is an island located in the Philippine Sea.	The average temperature is 23°C, which can drop to less than 5°C in December, January and February, but is warm for most months of the year.	Tourism, farming, fishing and other commercial activities
Reunion Island, France	Reunion is a large remote island located in the southern Indian Ocean, approximately 700km off the east coast of Madagascar.	Reunion's climate is warm and tropical and ranging from 15° to 35°C. Solar insolation in Reunion is 5.7kWh/m2/day on average.	Tourism, raw sugar
Akkan, Morocco	Akkan is an isolated hamlet (douar) in the province of Chefchaouen with 35 households, a school and a mosque.	It is hot and dry from April to October, while cool with some rain from November to March.	Agriculture and cattle grazing

Source: IEA-RTD, Renewable Energies for Remote Areas and Islands, 2012.

Island	Electrical Generation - Capacity	Load demand & growth
Bonaire, Netherlands	• Diesel: 5 x 2.8MW and 3 x 1MW • Wind: 1 x 330kW and 12 x 900kW • NiCad battery: 3 MW for 2 min	The microgrid is composed: • PV: 5.6 kWp • Back-up diesel genset: 8.2 kW • Battery bank: 72 kWh • Battery charge controller: 6 kW • Inverter/rectifier: 7.2kW
El Hierro, Canary Islands, Spain	• Diesel: 12.7MW • Hydro: 11.32 MW (6 MW pump hydro) • Wind: 11.5 MW	The microgrid is composed of: • PV: 5.6 kWp • Back-up diesel genset: 8.2 kW • Battery bank: 72 kWh • Battery charge controller: 6 kW • Inverter/rectifier: 7.2kW
Miyakojima, Japan	• Diesel: 19MW and 40MW • Gas turbine: 15MW • PV: 4MWp • Wind: 4.2 MW • NaS battery: 4MW, 200kWh	Power demand is 50MW.
Reunion Island, France	• PV: 200MW • Wind: 10MW • Hydro: 78 MW and other • Ocean thermal project: 20MW 	Reunion's annual load totaled 2,546 GWh, 60% fossil fuel-based, and approximately 40% renewable energy powered.
Akkan, Morocco	The microgrid is composed of: • PV: 5.6 kWp • Back-up diesel genset: 8.2 kW • Battery bank: 72 kWh • Battery charge controller: 6 kW • Inverter/rectifier: 7.2kW	Measured data from 2007 and 2009 indicates that total electricity consumption has remained approximately 5,550kWh/yr

Source: IEA-RTD, Renewable Energies for Remote Areas and Islands, 2012.

Island	Lessons Learned – Technical
Bonaire, Netherlands	It was recognised that the demand growth could be limited by considering more demand-side efficiency upgrades, with particular focus on tourism energy needs and the desalinization plants.
El Hierro, Canary Islands, Spain	Diesel use is limited to periods with no water nor wind.
Miyakojima, Japan	PV panels have been installed with a tilt of only 5 degrees due to limited space and to reduce damage by typhoons.
Reunion Island, France	A number of storage projects are underway in Reunion, from electric vehicles to hydro storage to MW-scale NAS batteries as well as residential-scale Li-ion units.
Akkan, Morocco	There was no electrical access before, but electrical demand has grown quickly. The EDA meters and generation system management unit improve overall system performance.

Island	Lessons Learned – Socio-economic
Bonaire, Netherlands	Local community education and technical skills capacity building are in place to enable the project to be maintained with local people.
El Hierro, Canary Islands, Spain	Capacity building programs on renewables and other environmental issues (recycling, forestry, and green entrepreneurship) have already taken place.
Miyakojima, Japan	A number of the renewable projects (including the 3MW solar project and Sadefune Wind Turbine farm) were installed along road which hosts the annual All Japan Triathlon Miyakojima race. This has helped promote tourism that can contribute to the local economy.
Reunion Island, France	The prioritization of renewable energy technologies and demonstration projects has created a number of jobs for local citizens and residents. Approximately 70% of components for solar hot water systems are manufactured locally.
Akkan, Morocco	A local technician was contracted for design and installation. The local technician has since been able to perform many maintenance tasks.

Island	Lessons Learned – Financial
Bonaire, Netherlands	-
El Hierro, Canary Islands, Spain	-
Miyakojima, Japan	-
Reunion Island, France	Reunion has benefited from the active engagement of government at many levels in providing direct and indirect support for renewable energy projects.
Akkan, Morocco	This is an important local infrastructure project but may compromise future battery replacements and the long term viability of the electrical system.

Source: IEA-RTD, Renewable Energies for Remote Areas and Islands, 2012.

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