



HYBRID SOLAR PV, MICRO-WIND WITH STORAGE

A Guideline Report
for Practitioners



Editorial

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Hybrid Solar PV, Micro-Wind With Storage - A Guideline Report for Practitioners.

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Hybrid Solar PV, Micro-Wind With Storage - A Guideline Report for Practitioners.

Reference project

Sustainable Energy For Security

Funded by

The European Union

Implemented by

United Nations Development Programme, Lebanon

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GLOSSARY OF TERMS

The following table provides an extended glossary of terms, including many terms that have not been used in this document. This extended glossary can be used in projects dealing with hybrid wind - photovoltaic power plants.

Wind Turbine (WT) Components	
Airfoil	The shape of the blade cross-section, which for most modern horizontal axis wind turbines is designed to enhance the lift and improve turbine performance
Alternator	A device that produces Alternating Current from the rotation of a shaft
Autonomous inverter	An inverter that supplies a load not connected to an electric utility. Also known as a "battery-powered inverter" or "stand-alone inverter"
Balance of System	In a renewable energy system, refers to all components other than the mechanism used to harvest the resource (such as photovoltaic panels or a wind turbine). Balance-of-system costs can include design, land, site preparation, system installation, support structures, power conditioning, operation and maintenance, and storage
Battery multi mode inverter	A type of inverter that is able to operate in both autonomous and grid-parallel modes according to the availability of the utility supply authority. This type of inverter initiates autonomous operation
Bearing	A device that transfers a force to structural supports. In a wind generator, bearings allow the Shaft to rotate freely, and allow the machine to Yaw into and out of the wind
Blade	The aerodynamic surface that catches the wind
Brake	Various systems used to stop the rotor from turning
Current control inverter	An inverter with an output current that is a specified sine wave produced by pulse-width modulated (PWM) control etc
DC converter	See Inverter
Dump load	A device where wind generator power flows when the system batteries are too full to accept more power, usually an electric heating element. This diversion is performed by a Shunt Regulator, and allows a load to be kept on the Alternator or Generator
Gearing	Using a mechanical system of gears or belts and pulleys to increase or decrease shaft speed. Power losses from friction are inherent in any gearing system
Generator	A device that produces Direct Current from a rotating shaft

Generator junction box	A junction box where the photovoltaic module circuits are electrically connected and where string protection devices are located
Grid-connected inverter	An inverter that is able to operate in grid-parallel with a utility supply authority. Also known as a grid-tied inverter
Grid-multi mode inverter	A type of inverter that is able to operate in both autonomous and grid-parallel modes according to the availability of the utility supply authority. This type of inverter initiates grid-parallel operation.
Hub	The center of a wind generator's rotor, which holds the blades in place and attaches them to the shaft
Inverter	A device that converts direct current (DC) to alternating current (AC). One of the family of components that is included in "power conditioner"
Junction box	An enclosure where circuits are electrically connected and where protection devices can be located
Lead-acid battery	An electrochemical electricity storage device commonly used in UPS and autonomous Wind-PV systems
Nacelle	The body of a propeller-type wind turbine, containing the gearbox, generator, blade hub, and other parts
Rotor	The rotating part of a wind turbine, including either the blades and blade assembly or the rotating portion of a generator
Shaft	The rotating part in the center of a wind generator or motor that transfers power
Storage	Accumulation of electricity in a non-electric form, which can be reconverted through the system to electricity
Tower	A structure that supports a wind generator, typically between 10m and 25m high from ground level, depending also on the size of the wind turbine
Utility interface disconnect switch	A switch at the interface between the photovoltaic system and the utility grid
Vented lead-acid battery	A lead-acid battery designed with a vent mechanism to expel gases generated during charging
Voltage control inverter	An inverter with an output voltage that is a specified sine wave produced by pulse-width modulated (PWM) control etc
Wind Power System	
Anemometer	A device to measure the wind speed
Autonomous operation	The operating mode in which loads are electrified solely by the Hybrid system and not in parallel with the utility. Also known as stand-alone or off-grid
Data logging and evaluation sub-system	The measurement and logic component(s) that register and process all relevant operational parameters and data of the plant to establish the day, month, and annual final yields, losses, and performance of the subsystems

Distribution system	An electrical facility and its components including poles, transformers, disconnects, isolators, and wires that are operated by an electric utility to distribute electrical energy from substations to customers. Also referred to as electric grid
Electric utility	The organization responsible for the installation, operation, and maintenance of all or some portions of major electric generation, transmission, and distribution systems
Genset	A colloquial term meaning “engine-generator set” consisting of an engine coupled to a rotating electric generator
Grid	The utility distribution system. The network that connects electricity generators to electricity users
Grid-connected operation	The operating mode in which a Wind Turbine is operating in parallel with an electric grid. Site loads will be electrified by either or both the utility or the plant. Electricity will be able to flow into the grid if the utility permits back feed operation
Grid multi mode operation	A grid-connected operation that is able to switch to an autonomous mode and back
Hybrid wind power system	See multi-source wind power system
Individual electrification plant	A small electric generating system that supplies electricity to one consumption point usually from a single energy source
Interconnection	The result of the process of electrically connecting a distributed generation plant to a distribution system in order to enable the two systems to operate in parallel with each other
Micro-grid	A grid that operates at less than 100 kVA of capacity and is electrified by a micro power plant
Micro power plant	A generating system that produces less than 100 kVA through the use of a single resource or a multi-source plant
Monitor and control sub-system	The logic and control component(s) that supervise(s) the overall operation of the plant by controlling the interaction between all sub-systems
Multi-source wind power system	A power system with wind generation operating in parallel with other electricity generators. Also called a "hybrid" system
Power conditioning sub-system	The component(s) that convert(s) electricity from one form into another form that is suitable for the intended application. Such a sub-system could include the charge controller that converts DC to DC, the inverter that converts DC to AC, or the charger or rectifier that converts AC to DC
Safety disconnect sub-system	The component(s) that monitor(s) utility grid conditions and open(s) a safety disconnect for out-of-bound conditions

Site	The geographical location of a plant
Storage sub-system	The component(s) that store(s) energy
Sub-system	An assembly of components. The following terms describe common subsystems
Wind farm	A group of wind turbines often owned and maintained by one company. Also known as a wind power system
Wind generator/turbine	A device that captures the force of the wind to provide rotational motion to produce power with an alternator or generator. It comprises a rotor, a generator or alternator mounted on a frame, a tail (usually), a tower, wiring, and the “Balance Of System” components
Wind generator sub-system	The components that convert wind energy into electricity using the kinetic energy of the wind
Wind Power System Performance Parameters	
AEP	Annual Energy Production, the calculated or measured energy delivered by a wind turbine. Expressed in kWh/y
Ampere-hour efficiency	The ratio of the amount of electrical charge removed during discharge conditions to the amount of electrical charge added during charge conditions in an electrical storage device
Average wind speed	The mean wind speed over a specified period of time
Betz Coefficient	59.3 percent. This is the theoretical maximum efficiency at which a wind generator can operate, by slowing the wind down. If the wind generator slows the wind down too much, air piles up in front of the blades and is not used for extracting energy
Charging efficiency	A generic term to express ampere-hour efficiency (or less commonly, watt-hour efficiency)
Cut-out wind speed	The wind speed at which a wind turbine ceases to generate electricity
Cut-in wind speed	The wind speed at which a wind turbine begins to generate electricity
Depth of discharge	A value that expresses the discharge of an electrical storage device. The ratio of the discharge amount to the rated capacity is generally used. Abbreviation: DOD. Units: dimensionless, usually expressed as a percentage (%)
Downwind	On the opposite side from the direction from which the wind blows
Efficiency	The ratio of output quantity over input quantity. The quantity specified is normally the power, energy, or electric charge produced by and delivered to a component. Symbol: η is commonly used. Units: dimensionless, usually expressed as a percentage (%)
Furling	A passive protection for the turbine in which the rotor folds either up or around the tail vane

HAWT	Horizontal axis wind turbine
Inverter efficiency	The ratio of the useful inverter output to its input
Inverter rated power	The power that can be supplied by the inverter at 25 °C. In grid-connected mode it refers to a continuous operating condition; in autonomous mode it usually refers to a 30' surge
Load	An electrical component that converts electricity into a form of useful energy and only operates when voltage is applied
Losses	The electrical power or energy that does not result in the service that is intended for the electricity
No load loss	Input power of the converter when its load is disconnected and output voltage is present
Normalized losses	The amount of time that a device or system would need to operate at its rated capacity in order to provide for system energy losses. These are commonly calculated from a difference in yields
Open-Circuit Voltage	The voltage that an alternator or generator produces when it is NOT connected to a Load
Overload capability	Output power level beyond which permanent damage occurs to a device or system. It is expressed by the ratio of overload power to rated load power for a period of time. Units: dimensionless (usually expressed as a percentage, %), and minutes
Partial load efficiency	The ratio of the effective inverter output power to its input power at a specified load.
Partial state of charge	A state indicating that an electrical storage device has not reached a full charge. Abbreviation: PSOC. Units: dimensionless, usually expressed as a percentage (%)
Performance ratio	The overall effect of losses on an array's rated output due to array temperature, incomplete utilization of the wind resource, and system component inefficiencies or failures. Commonly found by the quotient of the final system yield over the reference yield. Symbol: PR
Power coefficient	The ratio of the power extracted by a wind turbine to the power available in the wind stream
Power curve	A chart showing a wind turbine power output across a range of wind speeds
Power efficiency	The ratio of active output power to active input power
Rated efficiency	Pertaining to a device: The efficiency of a device at specified operating conditions, usually standard test conditions (STC). Pertaining to an inverter: The efficiency of an inverter when it is operating at its rated output
Rated output capacity	The output power of a wind machine operating at the rated wind speed
Rated wind speed	The lowest wind speed at which the rated output power of a wind turbine is produced

Residual capacity	The charge or energy capacity remaining in an electrical storage device following a partial discharge
Rotor diameter	The diameter of the circle swept by the rotor
Rotor speed	The revolutions per minute of the wind turbine rotor
Standby loss	The power drawn by a power conditioner when it is in standby mode. Units: W. Pertaining to stand-alone power conditioners: The DC input power. Pertaining to grid-connected power conditioners: The power drawn from the utility grid
Start-up wind speed	The wind speed at which a wind turbine rotor will begin to spin. See also Cut-in wind speed
State of charge	The ratio between the residual capacity and the rated capacity of a storage device. Abbreviation: SOC. Units: dimensionless, usually expressed as a percentage (%)
Storage rated capacity	The energy (or charge) that can be withdrawn from the storage device under specified discharge rate (time) and temperature conditions
Swept area	The area swept by the turbine rotor, $A = \pi R^2$, where R is the radius of the rotor
Tip speed ratio	The speed at the tip of the rotor blade as it moves through the air divided by the wind velocity. This is typically a design requirement for the turbine.
Upwind	On the same side as the direction from which the wind is blowing—windward
VAWT	Vertical axis wind turbine
Watt-hour efficiency	The ratio of the amount of electrical energy removed during discharge conditions to the amount of electrical energy added during charge conditions in an electrical storage device
Weibull distribution	A probability distribution function often used for wind regime presentation. This is the probability of the wind having a specified speed in a certain period, e.g. a year. This distribution function depends on two parameters, the shape parameter, which controls the width of the distribution and the scale parameter, and it depends on the average wind speed. The probability of wind occurrence over each year remains similar; hence, annual power production of turbines is reasonably predictable
Weighted average conversion efficiency	A method that estimates the effective energy efficiency. It is calculated as the sum of products of each power level efficiency and related weighting coefficients depend on a regional irradiance duration curve. When the plant is an autonomous type with a storage subsystem, the weighting coefficients depend on the load duration curve
Yaw	The movement of the tower top turbine that allows the turbine to stay into the wind
Weighted average conversion efficiency	A method that estimates the effective energy efficiency. It is calculated as the sum of products of each power level efficiency and related weighting coefficients depend on a regional irradiance duration curve. When the plant is an autonomous type with a storage subsystem, the weighting coefficients depend on the load duration curve

Solar photovoltaic components	
Autonomous inverter	An inverter that supplies a load not connected to an electric utility. Also known as a "battery-powered inverter" or "stand-alone inverter"
Battery management system	A battery management system is any electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its safe operating area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and / or balancing it. Abbreviation: BMS
Bypass diode (on a module level)	A diode connected across one or more cells in the forward current direction to allow the module current to bypass cells to prevent hot spot or hot cell damage resulting from the reverse voltage biasing from the other cells in that module
Crystalline silicon	A general category of silicon materials exhibiting a crystalline structure. Symbol: c-Si. (also single crystalline sc-Si and multi-crystalline mc-Si)
Current control inverter	An inverter with an output current that is a specified sine wave produced by pulse-width modulated (PWM) control etc
DC converter	An electronic component that changes the generator output voltage into a useable DC voltage
Dual mode inverter	A type of inverter that is able to operate in both autonomous and grid-parallel modes according to the availability of the utility supply authority. This type of inverter initiates autonomous operation
Generator junction box	A junction box in which the photovoltaic module circuits are electrically connected and where string protection devices are located
Grid-connected inverter	An inverter that is able to operate in grid-parallel with a utility supply authority
Grid-dependent inverter	An inverter that can only operate in grid-parallel with an AC electric grid. Also known as a grid-tied inverter
Hot spot	The intense, localized heating of a spot on a cell in a module where a breakdown of the junction on that cell has occurred due to an excessively high reverse voltage bias or by some damage. This creates a small, localized shunt path through which a large portion of the module current flows
Inverter	A system component that converts DC electricity into AC electricity. One of the family of components that is included in "power conditioner"
Junction box	An enclosure in which circuits are electrically connected and where protection devices can be located
Lithium ion battery	A lithium-ion (Li-ion) battery is an advanced battery technology that uses lithium ions as a key component of its electrochemistry
Maximum power point tracking	A control strategy for DC converters and PV inverters whereby the PV generator operation is always near the point of current-voltage, characteristic where the product of current and voltage yields the maximum electrical power under the operating conditions. Abbreviation: MPPT
Multi-string inverter	An inverter designed to operate with more than one string of PV modules. The output in AC can be connected in parallel with other similar inverters

Rated capacity STC	The PV module power delivered at the maximum power point at standard test conditions (STC)
Reference cell	A specially calibrated cell that is used to measure irradiance
Photovoltaic cell	The basic photovoltaic device. Colloquially referred to as a "solar cell"
Photovoltaic module or panel	The smallest complete environmentally protected assembly of interconnected cells. Colloquially referred to as a "solar module"
Storage	Accumulation of electricity in a non-electric form and which can be reconverted through the system to electricity
String inverter	An inverter designed to operate with only one string of PV modules. The output in AC can be connected in parallel with other similar inverters
Surge protective device	Device that is intended to protect the electrical apparatus from transient over-voltages and to divert surge currents. Also known as surge protection device
Utility interface disconnect switch	A switch at the interface between the photovoltaic system and the utility grid
Voltage control inverter	An inverter with an output voltage that is a specified sine wave produced by pulse-width modulated (PWM) control etc

Solar photovoltaic power plants

Autonomous operation	The operating mode in which loads are electrified solely by the PV plant and not in parallel with the utility. Also known as stand-alone or off-grid
Data logging and evaluation sub-system	The measurement and logic component(s) that register and process all relevant operational parameters and data of the plant to establish the daily, monthly and annual final yields, losses and performance of the subsystems
Distributed generation plant	The facility and equipment comprising an electricity generation plant that is interconnected to and operates in parallel with a distribution system
Distribution system	An electrical facility and its components including poles, transformers, disconnects, isolators and wires that are operated by an electric utility to distribute electrical energy from substations to customers. Also referred to as electric grid
Electric utility	The organization responsible for the installation, operation and maintenance of all or some portions of major electric generation, transmission, and distribution systems
Energy and Management System	Component with the objective of ensuring the proper management of the power plant (EMS)
Genset	A colloquial term meaning "engine-generator set" consisting of an engine coupled to a rotating Electric generator
Grid-connected operation	The operating mode in which a PV plant is operating in parallel with an electric grid. Site loads will be electrified by either or both the utility or the plant. Electricity will be able to flow into the grid if the utility permits back feed operation

Hybrid photovoltaic plant	Photovoltaic plant that includes battery storage and other generators such as diesel generators and/or the electric grid
Individual electrification plant	A small electric generating system that supplies electricity to one consumption point usually from a single energy source
Interconnection	The result of the process of electrically connecting a distributed generation plant to a distribution system in order to enable the two systems to operate in parallel with each other
Monitor and control sub-system	The logic and control component(s) that supervise(s) the overall operation of the plant by controlling the interaction between all sub-systems
Photovoltaic generator	A mechanically integrated assembly of modules or panels and its support structure that forms an electricity producing sub-system. This does not include energy storage devices or power conditioners. Also known as array
Photovoltaic generator sub-system	The components that convert light energy into electricity using the photovoltaic effect
Photovoltaic plant	A photovoltaic generator and other components that generate and supply electricity suitable for the intended application. The component list and system configuration varies according to the application, and could also include: power conditioning, storage, system monitoring and control, and utility grid interface. Also known as a photovoltaic system. Some of these plants are grid-connected and large, while others can also be small (micro plants), off-grid, or even diesel grid connected. The following terms describe common system configurations
Photovoltaic string	A circuit of series-connected modules
Power conditioning sub-system	The component(s) that convert(s) electricity from one form into another form that is suitable for the intended application. Such a sub-system could include the charge controller that converts DC. to DC., the inverter that converts DC. to AC., or the charger or rectifier that converts AC. to DC
Safety disconnect sub-system	The component(s) that monitor(s) utility grid conditions and open(s) a safety disconnect for out-of- bound conditions
Site	The geographical location of a plant
Storage sub-system	The component(s) that store(s) energy
Sub-system	An assembly of components. The following terms describe common subsystems

Solar photovoltaic plant performance parameters

Ampere-hour efficiency	The ratio of the amount of electrical charge removed during discharge conditions to the amount of electrical charge added during charge conditions in an electrical storage device
Charging efficiency	A generic term to express ampere-hour efficiency (or less commonly, watt-hour efficiency)
Depth of discharge	A value to express the discharge of an electrical storage device. The ratio of the discharge amount to the rated capacity is generally used. Abbreviation: DoD. Units: dimensionless, usually expressed as a percentage (%)

Efficiency	The ratio of output quantity over input quantity. The quantity specified is normally the power, energy, or electric charge produced by and delivered to a component. Symbol: η is commonly used. Units: dimensionless, usually expressed as a percentage (%)
Final annual yield	The total photovoltaic energy delivered to the load during one year per unit of installed PV capacity
Final plant yield	The net energy that was supplied during a given period of time by the photovoltaic generator normalized to its rated PV capacity. Symbol: Y_f
Generator rated capacity	The rated power generation of a photovoltaic generator, usually at STC
Generator yield	The photovoltaic energy generated per unit of installed generator capacity. Also referred to as array yield. Symbol: Y_a
Inverter efficiency	The ratio of the useful inverter output to its input
Inverter rated power	The power that can be supplied by the inverter at 25 °C. In grid-connected mode it refers to a continuous operating condition, in autonomous mode it usually refers to a 30' surge
Load	An electrical component that converts electricity into a form of useful energy and only operates when voltage is applied
Losses	The electrical power or energy that does not result in the service that is intended for the electricity
Module mismatch loss	The difference between the total maximum power of devices connected in series or parallel and the sum of each device measured separately under the same conditions. This arises because of differences in individual device I-V characteristics. Units: W or dimensionless expressed normalized
No load loss	Input power of the converter when its load is disconnected and output voltage is present
Normalized losses	The amount of time that a device or system would need to operate at its rated capacity in order to provide for system energy losses. These are commonly calculated from a difference in yields
Open circuit voltage of a photovoltaic generator	The open circuit voltage at STC of a PV generator, and is equal to: $V_{OC\ pvg} = V_{OC\ MOD} \times M$, where M is the number of series-connected PV modules in any PV string of the generator. Abbreviation: $V_{OC\ pvg}$
Overload capability	Output power level beyond which permanent damage occurs to a device or system. It is expressed by the ratio of overload power to rated load power for a period of time. Units: dimensionless (usually expressed as a percentage, %), and minutes
Partial load efficiency	The ratio of the effective inverter output power to its input power at a specified load
Partial state of charge	A state indicating that an electrical storage device has not reached a full charge. Abbreviation: PSoC. Units: dimensionless, usually expressed as a percentage (%)
Performance ratio	The overall effect of losses on an array's rated output due to array temperature, incomplete utilization of the irradiation, and system component inefficiencies or failures. Commonly found by the quotient of the final system yield over the reference yield. Symbol: PR

Plant rated power	Pertaining to PV autonomous plants: The power generated when connected to a rated load. Pertaining to PV grid-connected plants: The power that can be injected under standard operating conditions
Power efficiency	The ratio of active output power to active input power
PV generator capture losses	The normalized losses due to photovoltaic generator operation, found by the difference between the reference yield and the generator yield. It includes mismatch losses, temperature effect, and non dispatchable yield. Symbol: L_c
Rated efficiency	Pertaining to a device: The efficiency of a device at specified operating conditions, usually standard test conditions (STC). Pertaining to an inverter: The efficiency of an inverter when it is operating at its rated output
Reference yield	The amount of time that the irradiance would need to be at reference irradiance levels to contribute the same incident irradiation that actually occurred. It is calculated from the quotient of the total irradiation over the reference irradiance Symbol: Y_r . NOTE: If $G_{l,ref} = 1 \text{ kW/m}^2$ then the irradiation is expressed in kWh/m ² over any period of time is numerically equal to energy as expressed in kWh/kW over that same period. Thus Y_r would be, in effect, «peak sun-hours» over that same period
Residual capacity	The charge or energy capacity remaining in an electrical storage device following a partial discharge
Short circuit current of a photovoltaic generator	The short circuit current at STC of a PV generator, and is equal to: $ISC_{pvg} = ISC_{STC MOD} \times S_g$, where S_g is the total number of parallel-connected strings in the PV generator
Standard test conditions (STC)	Reference values of in-plane irradiance ($G_{l,ref} = 1000 \text{ W/m}^2$), air temperature (25°C), and air mass (AM =1,5) to be used during the testing of any photovoltaic device. Abbreviation: STC
Standby loss	The power drawn by a power conditioner when it is in standby mode. Units: W. Pertaining to stand-alone power conditioners: The DC. input power. Pertaining to grid-connected power conditioners: The power drawn from the utility grid
State of charge	The ratio between the residual capacity and the rated capacity of a storage device. Abbreviation: SoC. Units: dimensionless, usually expressed as a percentage (%)
Storage rated capacity	The energy (or charge) that can be withdrawn from the storage device under specified discharge rate (time) and temperature conditions
Voltage of a photovoltaic generator	The PV generator voltage is considered to be equal to open circuit voltage under worst case conditions
Watt-hour efficiency	The ratio of the amount of electrical energy removed during discharge conditions to the amount of electrical energy added during charge conditions in an electrical storage device
Weighted average conversion efficiency	A method of estimating the effective energy efficiency. It is calculated as the sum of products of each power level efficiency and related weighting coefficients depending on a regional irradiance duration curve. When the plant is an autonomous type with a storage subsystem, the weighting coefficients depend on the load duration curve

Yield	The equivalent amount of time that a plant would need to operate at its rated capacity at STC in order to generate the same amount of energy that it actually generates. A yield indicates actual device or system operation normalized to its rated capacity
Environmental parameters	
Ambient temperature	The temperature of the air surrounding a PV generator as measured in a vented enclosure and shielded from solar. Symbol: T_{amb} . Unit: °C
Angle of incidence	The angle between the direct irradiant beam and the normal to the active surface
Azimuth angle	The projected angle between a straight line from the apparent position of the sun to the point of observation and a horizontal line normal to the equator. This is measured from due north in the southern hemisphere and from due south in the northern hemisphere. Negative azimuth values indicate an eastern orientation and positive values a western orientation. Symbol: θ
Global irradiance	Irradiance on a horizontal surface. This equals horizontal direct irradiance plus horizontal diffuse irradiance
In-plane irradiance	Total irradiance on the plane of a device. Symbol: G_I
Irradiance	Electromagnetic radiated power incident upon a surface, most commonly from the sun or a solar simulator. Symbol: G . Unit: W/m^2
Irradiation	Irradiance integrated over a specified time interval. Symbol: H . Unit: J/m^2
Solar elevation angle	The angle between the direct solar beam and the horizontal plane. Symbol: β
Solar energy	Common term meaning irradiation
Tilt angle	The angle between the horizontal plane and the plane of the module surface
Testing and certification	
Acceptance testing	Site-specific testing to assure acceptable performance as required by the technical specifications
Certificate of conformity	A label, nameplate, or document of specified form and content, directly associated with a product or service on delivery to the purchaser, attesting that the product or service is in conformity with the requirements of the certification program (e.g., with the referenced standards and specifications).
Inspection	Evaluation for conformity by measuring, observing, testing, or gauging the relevant characteristics as required by the technical specifications
Tests	Technical operations to establish one or more characteristics of a given product or service according to a specified procedure
Verification	Confirmation by examination and recording of physical evidence that specified requirements have been met
Verification testing	Site-specific, periodic testing to assure continued acceptable performance

Miscellaneous

Class II equipment	Equipment in which protection against electric shock does not rely on basic insulation only, but in which additional safety precautions such as double insulation or reinforced insulation are provided, there being no provision for protective earthing or reliance upon installation conditions
Class III equipment	Equipment in which protection against electric shock relies on supply at SELV and in which voltages higher than those of SELV are not generated
Double insulation	Insulation comprising both basic insulation and supplementary insulation
Electromagnetic interference	The condition where electromagnetic energy interferes with the proper operation of equipment. Abbreviation: EMI
Extra-low voltage (ELV)	Voltage not exceeding 50 V AC. and 120 V ripple free DC (a ripple content not exceeding 10% r.m.s). Some national standards consider 75 V DC as a maximum. Considering ELV status, VOC of the PV generator must be used
Fuel Reduction Mode	Mode of operation when the PV plant works in parallel to the diesel genset with the objective of reducing the fuel consumption
High voltage (HV)	Voltage exceeding low voltage
Lithium iron phosphate	A type of Li-ion battery's chemistry typically used in hybrid power plants Abbreviation: LFP
Low voltage (LV)	Voltage exceeding extra-low voltage, but not exceeding 1,000 V AC or 1,500 V DC
Safe extra low voltage (SELV)	An extra-low voltage system which is electrically separated from earth and from other systems in such a way that a single fault cannot give rise to the risk of electric shock
Total harmonic distortion	The ratio of effective signal of total harmonic to effective signal of basic frequency. Units: dimensionless, usually expressed as a percentage (%)

01

INTRODUCTION

1.1. The Project

The European Union funded, United Nations Development Program (UNDP) implemented, “Sustainable Energy for Security” (SE4S) project focuses on strengthening the security and well-being of the Lebanese Armed Forces (LAF), specifically the LAF stationed in the North-Eastern border region of Lebanon. The aim of the project is the provision of sustainable energy solutions that, first and foremost, increase the LAF’s energy autonomy in the region and enhance the general energy services that achieve a higher ability to observe and carry out the respective security-based operations.

Additionally, these actions build on the Lebanese Armed Forces Sustainable Energy Strategy of 2017 (EU-UNDP CEDRO 4, 2017), endorsed by the Lebanese Ministry of Defense and the LAF.

The LAF Sustainable Energy Strategy endorses Lebanon’s Nationally Determined Contribution (NDC) commitment under the Paris Climate Change Agreement of 2015, and commits the LAF built environment to the following targets to be reached by 2030:

- 20% of its total electricity consumption is to be generated from renewable energy sources
- 20% of its total thermal consumption is to be generated from renewable energy sources

1.2. 10% reduction in energy use per sqm Guideline Report

This guideline report focuses on hybrid wind-PV power plants with battery energy storage, back-up diesel generators, and a potential grid connection (when available). The objective of this report is to guide a client and/or any tendering authority or related institution towards the best practices and lessons learned in the development of the hybrid power plants.

The scope of the guideline report includes the project phases of design, procurement, installation, commissioning, operation, and maintenance.

The envisioned hybrid power plants have a continuous power capacity below 500 kWac, with AC and DC voltage ranges within the Low Voltage regime.

02

SIZING AND DESIGN

2.1. Site visit

The objective of the initial site visit is to gather all information required to do the demand assessment and the design and sizing of the

hybrid power plant. It is recommended to have at least one initial visit planned in the project. During the visit, the following basic information shall be collected (see Table 1):

Table 1. Information to be collected during the site visit

CATEGORY	INFORMATION REQUIRED	
General	<ol style="list-style-type: none"> 1. GPS coordinates 2. Aerial photographs 3. Single Line Diagram of the existing installation (if available); and if not, information to build an SLD 4. Accessibility description 5. Presence of water supply 6. Topographic maps (Digital Elevation Model) 	
PV generator	Ground-mounted	Roof-mounted
	<ol style="list-style-type: none"> 1. Size of land area available (length, width, and area) 2. Type of soil available 3. Terrain slope (if any) 4. Drainage of the site 5. Distance from the point of connection 6. Presence of underground electrical cables, water, and waste pipes at or close to the site 7. Shading elements near the site, including their location and physical dimensions (buildings, water tanks, poles, antennas, etc.) 	<ol style="list-style-type: none"> 1. GPS coordinates 2. Type of roof available 3. Size of roof area available 4. Type of roofing material, including waterproofing materials 5. Profile of roofing material 6. Orientation and tilt of roof. Location of shading obstacles and their physical dimensions (chimneys, skylights, antennas, etc) 7. Maximum weight capacity (kg/m²)

Loads	<p>General:</p> <ol style="list-style-type: none"> 1. Categorization of the existing loads 2. Potential future demand increase <p>If conducting a top-down demand assessment (see Section 2.2):</p> <ol style="list-style-type: none"> 3. Total load profile measurement (at least 1 day), including the load of each phase 4. Monthly electricity bills (grid, diesel) <p>If conducting a bottom-up demand assessment (see Section 2.2), for each load:</p> <ol style="list-style-type: none"> 5. Type 6. Quantity 7. Nominal power and surge power (both active and reactive) 8. Operating time (hours per day, days per week, weeks per month, months per year)
Diesel generator(s) (if any)	<ol style="list-style-type: none"> 1. Manufacturer, model and technical specifications (power, voltage, frequency, rpm, fuel consumption, reverse power protection, etc) 2. Location within the premises 3. Date of installation, total number of hours in operation, daily hours of usage. 4. Controllers make and model 5. Current operational modes and O&M activities
Utility grid (if any)	<ol style="list-style-type: none"> 1. Service quality assessment: number of service hours per day, voltage range, harmonic distortions (in case of sensitive loads), frequency of blackouts or brownouts
Electrical installation	<ol style="list-style-type: none"> 1. Existing switchboards: state, rated amperage 2. Available space for extra connections in the envisioned point(s) of connection (e.g. at the main distribution board) 3. Earthing system type and assessment of potential improvement 4. Assessment of re-wiring needs (in case of dividing the loads into critical and non-critical, e.g.) and/or potential retrofit of the installation

If there are several uncertainties during the site visit and much of this information cannot be collected, it is recommended to arrange a site visit during the bidding process so that potential contractors can assess the site themselves and collect any necessary information to make their offer.

2.2. Demand assessment

During this phase, the current and future site's electricity demand is quantified. It shall be noted that the demand can change due to the project's implementation. One reason could be that the demand increases because new loads are added, such as an air-conditioning system for the battery room. Another reason could be that the load demand is purposely adapted to the nature and limitations of the PV hybrid plant during project design through the so-called 'demand side management' strategies.

On one hand, the efficiency of the plant is highest during daytime, therefore some loads might be time-shifted to the central hours of the day. On the other hand, the energy storage capacity of the plant is limited, and some strategies such as load shedding of non-critical loads might be opted for to increase the reliability of the service.

Therefore, understanding the loads is an essential step during the demand assessment phase.

The categorization of the loads can be done in different category groups:

- Priority level.
 - Critical loads, which are those which power supply shall be maintained under any circumstances and should not ever be interrupted.
 - Priority loads, which are those to which preference should be given in case of limited power supply (intermediate priority level).

Non-critical loads, which are those that can be interrupted first in case of limited power supply.

- Time usage
 - Base loads, which are those that have a continuous energy demand throughout the day.
 - Deferrable loads, which are those that require a certain amount of energy within a given period (i.e. not continuous throughout the day) but the exact timing is not important and therefore can be deferred in time.
 - Interruptible loads, which are those that can be interrupted.
- Type of current, AC or DC.
- Number of phases, single phase or three-phase.

The quantification of the loads can be typically done via two different approaches, a top-down approach and a bottom-up approach. These can also be combined.

In a top-down approach, the site's total load is measured. Depending on the site's electrical configuration, this could be more easily done at the main distribution board where all the loads are connected, at the grid connection point, or at the diesel generator's output, among other possibilities.

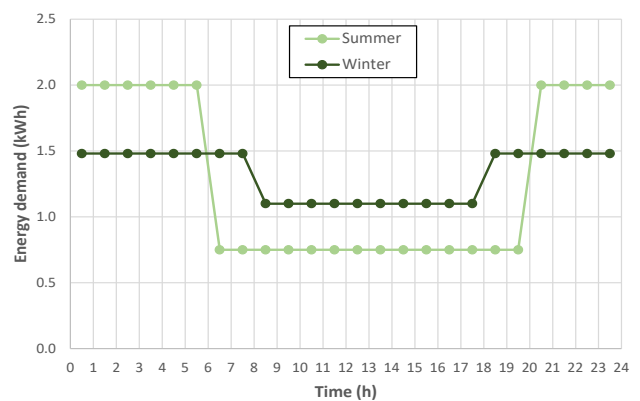
It is important to measure the load demand on each phase to assess the load unbalance, which can impact the sizing of the battery inverter

In a bottom-up approach, the energy usage of each appliance is calculated by multiplying its power by the daily hours of usage (see Figure 1). A total load demand curve can then be built by adding the loads of all the appliances together.

In both cases, the assessment shall consider the power surges required by some loads (which may affect the desired overload capabilities of the battery inverter) and the load variation within the year.

An analysis of the monthly electricity invoices and diesel consumption can help in figuring out the monthly variations in case there are not enough resources to do a long measurement campaign or a detailed analysis of each load's variation within the year.

Figure 1. Example of a load profile estimated by a bottom-up approach during UNDP's "Sustainable Energy for Security" project



2.3. Electrical configuration

A proper assessment of the energy yield of Small Wind Turbines (SWTs) requires an analysis of wind turbine type and assessment of the available wind resources, including the effect of local site characteristics, such as terrain and obstacles. Wind resource is much more variable (both temporarily and spatially) than solar resource. This means that, on one hand, it is more difficult to evaluate and, on the other hand, small variations in the site may bring important variations in the wind resource.

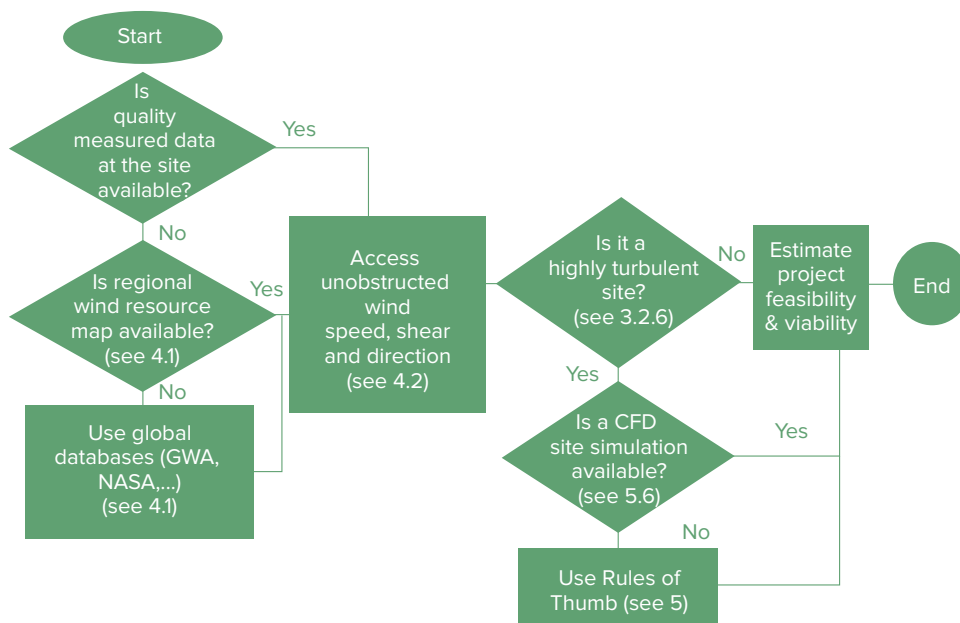
2.3.1. Wind Resource Assessment Methods

There are a variety of methods to assess wind resource, and their costs range from low to high, with the cost being directly related to the level of reliability of the assessment. The methods of assessing the wind resource usually stem from using a general wind map and using that wind speed information to form the basis of a production estimate.

Another approach is to use a commercial wind resource model to identify, more “precisely,” the annual wind speed range. A third approach is to assess wind measurements from nearby projects, wind resource towers, airports, or other weather stations. Wind maps typically provide a basis for the wind speed, which is the other important factor in understanding production. These three approaches do not take into account the impact of local micro-siting and the dramatic effect that it has on a Small Wind Turbine (SWT). The only method where the wind resource is truly quantifiable and accounts for obstacle, terrain, wind direction,

and blockages measures the wind at the exact location and exact hub height of the proposed small wind installation. Even though on-site wind measurements are the most reliable method of assessing the local wind resource, it is expensive and time-consuming, and the cost is not justified for SWTs. Historically, the cost of wind measurement equipment and analysis has been prohibitive for Small Wind Turbines. Recently, new wind resource measurement approaches have been developed, including lower cost wind measurement equipment and towers and new drone technology. Figure 2 presents the process for quantifying the site.

Figure 2. Flow of steps to quantify the site from the wind resource point of view



Methods to cope with these cost restrictions are listed as follows: Use of reanalysis data, nearby Met office statistics, or regional wind maps specifically for SWT implementation; and choose a site for the wind turbine as free from obstacles as possible.

Given the temporal variability of the wind, it is important to know the time distribution over a period. Meteorological stations may be an option to collect the required data; however, they are not always close to the site, or they are not accessible to the public. In this case,

it is feasible to use reanalysis databases. Reanalysis data use assimilation processes to combine observed (or measured) data obtained from satellites, ships, sensors, and weather stations with numerical models.

Since the observed data are unevenly distributed over the Earth, numerical meteorological models allow the estimation of the state of different layers of the atmosphere for a certain place and time period using a regular grid. With this approach, it is possible to generate a time series of gridded atmospheric parameters,

such as air temperature, pressure, and wind at different altitudes; and, it is also possible to generate a time series of surface parameters such as rainfall, soil moisture content, ocean-wave height, and sea-surface temperature.

Some of the leading global data sets are CFSR (Climate Forecast System Reanalysis)¹, MERRA-2 (Modern-Era Retrospective Analysis for Research and Applications)², and ERA5³ (European Center for Medium-Range Weather Forecast/ECMWF Reanalysis v5).

Using reanalysis data also allows the easy performance of long-term analysis on the viability of the inclusion of wind generation in hybrid diesel micro-grids since it provides data for decades.

2.3.2. Small Wind Resource Assessment

In the case of performing a measurement campaign, in order to summarize the high-quality requirements in wind measurement, international standards have been developed, such as the MEASNET guidelines. MEASNET is an international network of measurement institutes, which developed the guideline ‘Evaluation of site-specific wind conditions.’

This guideline describes the process of site assessment including data collection, evaluation, and interpretation. The MEASNET guideline refers to IEC 61400-12-1 (Wind Energy Generation Systems – Part 12-1: Power Performance Measurements of Electricity Producing Wind Turbines) and focuses on data quality, plausibility, and integrity.

Even for SWT there are some guidelines available for site assessment, that cover most of the aspects that may apply when considering the inclusion of a SWT in a system.

More detailed guidelines for site turbulence influence on the SWT estimated production can be found in dedicated guidelines.

However, one of the main limitations for considering wind generation in hybrid systems in the range that is being considered in this work is commonly the lack of reliable wind data necessary to evaluate its convenience.

Nowadays, there are both global and local (usually at a national level) wind atlases. In this case, the no-data situation, which was not rare a few years ago, is almost extinguished. However, to have a minimum performance evaluation of wind generation within a hybrid system, wind resource characterization is not a universal fit: Characterization needs to include detailed spatial and temporal information. It should be noted that the best method to achieve this goal is through an on-site wind measurement campaign.

To be able to assess wind generation in a hybrid system, at least hourly average wind speed variation is required to evaluate its match with demand and other forms of generation profiles from an energy balance point of view.

Other short-term phenomena (dynamics and/or transients) would require even higher time resolutions, but they are out of the scope of this application detailed under this publication since this approach requires long-term storage. Global and local wind atlases may only collect information on the overall yearly wind regime or even on the monthly average wind speed.

In the latter, some softwares (such as HOMER Pro) may generate hourly synthetic series from monthly average values of wind speed; therefore, software simulations might be a preliminary approach.

¹ The NCEP Climate Forecast System Version 2 (CFSv2). Available online: <https://cfs.ncep.noaa.gov>

² MERRA 2 data are available online: www.renewables.ninja

³ ECMWF—Climate Reanalysis Web Page. Available online: <https://www.ecmwf.int/en/research/climate-reanalysis>

Regarding the site assessment, wind direction estimation is also necessary. As for the wind rose, the Global Wind Atlas could be used.

The novelty lies in the availability of reanalysis data derived from satellite observations, such as MERRA-2 and ERA5, both globally and freely available / accessible, and they both provide relatively sufficient time resolution (one hour) wind speed and wind direction data, but with an insufficient spatial resolution of several square kilometers.

Typically, for an SWT, the acceptable spatial resolution for analysis ranges between hundreds of square meters, up to 1 km². However, these data could be used as input for downscaling (also considering the available information on roughness and DEM, Digital Elevation Models) by generating higher spatial resolutions down to several hundred meters.

Although all these sources of information are freely available making them accessible to everyone wanting to do these simulations / this work (this is good news for SWT), some commercial tools are available, which provide a simpler analysis / simulation.

As a reference, EMD in Europe and UL in the US offer different software solutions that obtain hourly wind resource estimation for any point (Windographer and WindNavigator, in the case of UL; WindPro, for EMD) with a reasonable spatial resolution: UL offers a Typical Year Time Series Short Term Data set using the AWST MASS model, and it is scaled to 200 m resolution to represent a 365 day sample over a 15 year period; while with EMD's full WindPRO modeling chain, it is possible to downscale the data from the global level to the mesoscale level and, further, to the micro-scale level (e.g., using the WindPRO scaler options) to a 250 m resolution or even 100 m resolution with WAsP.

These two software groups also offer two particular applications that are especially suitable for the assessment of SWT in hybrid systems: MyWindTurbine (EMD) was designed for the evaluation of the influence of obstacles in SWT production, which is a key issue for SWT; and HOMER Pro (recently acquired by UL) is the reference for hybrid systems optimization. In the latest version of HOMER Pro 3.14.2, there is a link to WindNavigator (UL software for wind resource estimation) that, while it is not yet available, opens the door to connect both applications.

One estimate of the cost to have a site modeled in the United States in 2016 was approximately \$500. The model utilizes static wind maps, a gross approximation using annual average site wind speed and micro-site adjustments. A characterization using myWindTurbine software costs around 60 EUR/site. However, care should be taken with respect to the temporal needs in hybrid systems previously described, which may not be covered by these solutions.

2.4. Sizing methodology – Configuration selection

The methodology described here for the sizing of hybrid systems only deals with some technical considerations of the design related to the consideration of wind technology, which involves other key aspects such as social, environmental, management, contractual, quality assurance, training, and some other aspects as well.

The methodology suggests three stages: Data collection, sizing study, and the implementation stages, which will be described below.

2.4.1. Stage (a) Data Collection

At this stage, the main input to the design process are gathered: A site visit, the demand assessment, and the wind resource assessment, which have already been covered in previous sections.

2.4.2. Stage (b) Sizing study

It is advisable to perform an initial screening of the component sizes, both at a simple spreadsheet level and at a conceptual design level; it is recommended to prepare the information for its use in the sizing tool (HOMER Pro is proposed and utilized in the present cases detailed under this publication, which in the most recent version incorporates the Optimizer, and the automatic tool to search for the optimal configuration); in parallel, it is highly recommended to have an estimate of the result commonly calculated / evaluated using spreadsheets. This spreadsheet may also be useful if a business model analysis is required, since HOMER Pro does not include it.

However, sizing tools require higher possibilities, such as the following: Hourly basis simulation, which usually requires synthetic generation of data to compensate the possible lack of measured data; sensibility analysis, to cope with the uncertainty of the inputs; more detailed (but still friendly) models of components, including all the necessary parameters to complete the study while maintaining it at the lowest degree of complexity in order to make it useful; commercial components databases, with the capability to create new ones.

At this level, both tools options are available: commercial tools (either free or requiring a fee), such as HOMER PRO tool from Homer Energy by UL (company), an international reference; or self-designed proprietary tools, which take time and effort to develop but may be necessary if a specific analysis has to be made, such as the dynamic analysis.

Real dynamic analysis is not usually necessary for these types of systems since they are inverter dominated micro-grids based on long-term battery storage using commercial power electronics solutions, which provide the necessary power quality and electrical stability to the system.

This is however recommended in diesel - dominated systems without storage. However, the pseudo-dynamic simulation is recommended to assess the behavior of the battery, mainly taking into account the influence of wind generation. The stability of the system remains the designer's responsibility since it cannot be visualized / analyzed through the feasibility study. The expected result of this design stage is the selected configuration, along with its detailed behavior in terms of stability and performance; to achieve this result, the designer should carry out a cyclic design process, modifying sizes or parameters until the system performance meets the requirements.

2.4.3. Stage (c) Implementation Project

Once the configuration and equipment are selected, all of the systems' components are calculated and chosen through the "Sizing study" stage followed by the preparation of the necessary technical documentation for the deployment of the installation: Schemes, plans, etc. This stage is purely an engineering stage; there is no dedicated software for this step, but programs of general use in engineering are commonly applied, such as Autocad, Project, etc. However, some technology specific software may be necessary: For example, in order to design the PV generator (if it is present in the design), it is necessary to design the detailed configuration of the generator, which is not provided by HOMER Pro.

For the selection of the final components, here are critical characteristics / requirements detailed in the following subsections.

2.4.3.1. The Small Wind Turbine (WT)

A unique definition does not exist for what an SWT is, in terms of size, but a more or less universal convention is that it refers to wind turbines smaller than 100kW. Within this range, Table 2 shows the sub-classifications.

Table 2. Classification of SWT

Rated power (kW)	Rotor swept area (m ²)	Sub-category
$P_{\text{rated}} < 1 \text{ kW}$	$< 4.9 \text{ m}^2$	Pico wind
$1 \text{ kW} < P_{\text{rated}} < 7 \text{ kW}$	$< 40 \text{ m}^2$	Micro wind
$7 \text{ kW} < P_{\text{rated}} < 50 \text{ kW}$	$< 200 \text{ m}^2$	Mini wind
$50 \text{ kW} < P_{\text{rated}} < 100 \text{ kW}$	$< 300 \text{ m}^2$	(No clear definition adopted yet)

The values that define the ranges for this classification have been chosen from the standards and legislation affecting SWTs. The value of 40 m² was the limit established in the first edition of the IEC-61400-2 standard (Wind turbine generator systems – Part 2; Safety of small wind turbines, 1st Edition) and is the range intended at the present time for the integration of SWT into the built environment; the 200 m² limit was established in the second edition of the above-mentioned IEC-61400-2 standard in 2006 (Wind turbines – Part 2; Design requirements of small wind turbines, 2nd Edition) and includes most SWT applications. Finally, the 100 kW limit is defined in many countries as the maximum power that can be directly connected to the low voltage grid. The pico-wind range is commonly accepted as those SWTs smaller than 1 kW (Kindly refer to Net Metering Guidelines.).

Despite being more uncertain, models and topographical background data are at a level of quality that makes the calculated wind resources valuable for SWT projects. Having determined the wind resources, the second source of uncertainty in energy yield calculations is the wind turbine type, or more specifically the power curve of the wind turbine.

Many countries have standards for how wind turbine manufacturers should collect and process data to produce certified power curves; this improves the the power curves' accuracy that could otherwise be too "optimistic."

Quality assurance has proven to be indispensable for establishing an enabling environment for a rapid uptake of renewable energy technologies. Quality assurance of standards are intended to ensure that products and services perform as expected and also includes the mechanisms to verify that such requirements are fulfilled, e.g., testing and certification. Quality assurance is of particular importance for SWT: A great effort has been conducted during the last two decades to increase the SWT quality, and there are many reliable models in the market, but it is also possible to find many commercial models that have not been certified nor tested.

Another important issue related to SWTs is the availability of wind turbines, which refers to both the available sizes and the available manufacturers. Before choosing an SWT, it is advisable to be informed about sizes and maintenance support service in the area. This limits the number of available wind turbines for the design. An added layer of difficulty is the frequently changing characteristics of the SWT

market (For instance, from the around 20 small wind turbines manufacturers in Spain in 2014, only eight are still active in this field in 2020.).

Information on available manufacturers and models should be updated frequently in order to be aware of the present situation. Both myWindTurbine and HOMER Pro include SWT databases, which are useful as a reference, but both of them are neither completely updated nor exhaustive.

2.4.3.2. The other components

Here are some notes related to the implementation of the other components:

- Li-ion batteries. When sizing Li-ion batteries, it should be noted that different manufacturers offer different maximum DoD values which can range from 80 to 100%. The battery's lifetime should be estimated depending on the DoD design, which can sharply decrease when moving towards DoD = 100%.
- PV and battery inverters in an AC-coupled system. The manufacturers guidelines should be strictly followed when designing the ratio between the PV inverter power and the battery inverter power in an AC-coupled system. Nowadays, ratios range between 0.8 and 2. Surpassing manufacturer's ratios could void equipment warranties or lead to system instability.
- Battery inverters. If motors and compressors are present among the loads, the battery inverter shall be able to provide their reactive power and surge power requirements. Note that the overload capacity of the inverter varies greatly among different manufacturers.
- Cabling and protections. Sizing cabling and protections can be done by following the latest edition of IEC 60364-7-712 "Low voltage electrical installations - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems."

Aspects such as installation, commissioning, operation and maintenance, or monitoring will be covered in this document in subsequent sections.

2.4.4. Configuration selection

The common feature in all the systems covered in this publication is the presence of diesel generation. However, hybrid systems existing today can be classified from a technical point of view into diesel-dominated and inverter-dominated hybrid systems, depending on which component is in charge of grid stability.

2.4.4.1. Diesel dominated hybrid systems

Diesel engines have traditionally been one of the main options when setting up power stations in rural and remote areas. However, the important drawbacks of this option (such as the rising cost of diesel fuel and carbon emissions concerns) when compared to renewable energy, make the case for the inclusion of renewable energies in diesel dominated grids.

In today's detailed systems, the grid is formed by diesel generator(s). In fact, the common case is that there is an already existing grid supplied by (a) diesel engine(s), where a renewable energy system is retrofitted. Larger systems are usually composed of more equipment with larger capacities that allow for an economy of scale, and therefore lower power costs.

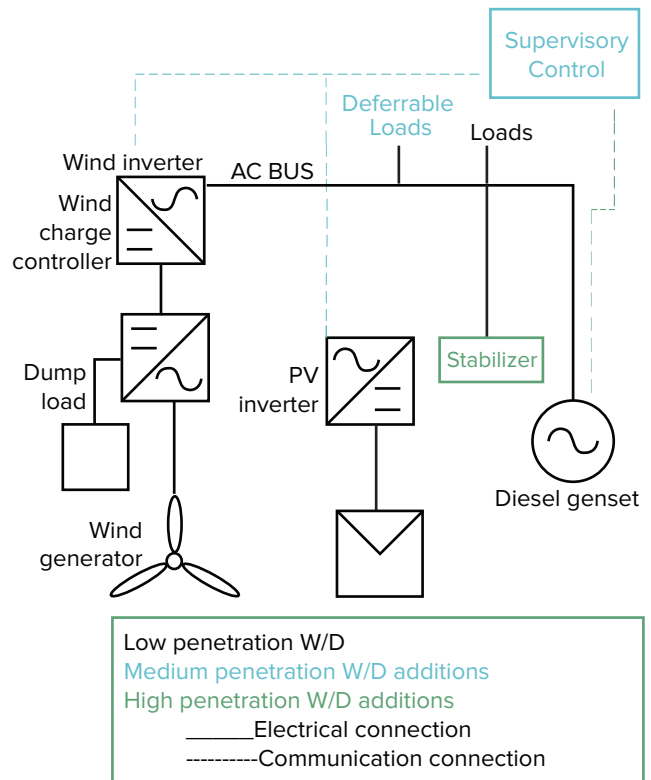
The system design is strongly related to the amount of energy that is expected from renewable sources (system penetration), which will define the methods used to control the power system. System penetration can be defined either as Instantaneous penetration (Renewable Power Output divided by the Load Power) or as Average penetration (Renewable Energy Output divided by the total Load Energy over a given time period, typically a month or a year). Instantaneous penetration relates to the power system's complexity to maintain

relates to steady state general system operation characteristics. Three different types of wind-diesel (W/D) systems can be distinguished, according to the proportion of wind-use in the system:

- Low penetration W/D systems, which do not require additional modifications to the diesel-only grid (usually an existing system) since the diesel engine runs continuously and its controls can cope with the control of the system in the W/D mode of operation without significant modification.
- Medium penetration W/D systems, which require the inclusion of some supervisory control capabilities (usually the regulation of deferrable loads and/or the regulation of the wind generation) for the moments when wind generation is higher than load consumption. It should be noted that deferrable loads could be any load applied to manage the demand and hence improve system efficiency; this could be: Pumping systems, heating / cooling systems, electric vehicles, etc.
- High penetration W/D systems, which require the addition of complex control strategies and devices (stabilizer) in order to guarantee the stability of the system in the wind-only mode, (in other words when the diesel genset is shut off).

The three types of W/D systems are shown in Figure 3 below: As the renewable generation penetration increases, new components and capabilities are added, maintaining the ones of lower penetration levels. A PV generator has been added, for a broader vision of the hybrid system, but the presence and size of the different generators will come from the sizing stage of the system.

Figure 3. Scheme for the three Wind Diesel systems types



2.4.4.2. Inverter dominated hybrid systems

Most of the existing hybrid systems can be included in this group, which is mainly characterized by the inverters as the grid forming unit, and the use of long-term storage (in the past, usually lead acid batteries) as the main source to stabilize the grid; fossil fuel generators are present, but as a back-up unit, and usually with the option of directly supplying the load and bypassing the inverter, if needed (decision to be made at design stage). From a configuration point of view, size is not an issue for this configuration, however, it remains a very important criterion in terms of component availability, cost and design. From a technical point of view, systems in this category can be grouped into three different types: Single fixed master (use unidirectional inverter – which would translate into components being connected at the DC busbar level), Changing fixed master (use bidirectional inverter – hence allowing more flexibility in terms of connection), and Multimaster (use distributed inverters and control – even higher flexibility).

Inverter dominated architectures are commonly used for systems lower than some hundreds of kW, mainly due to the problems they face when integrating larger battery systems.

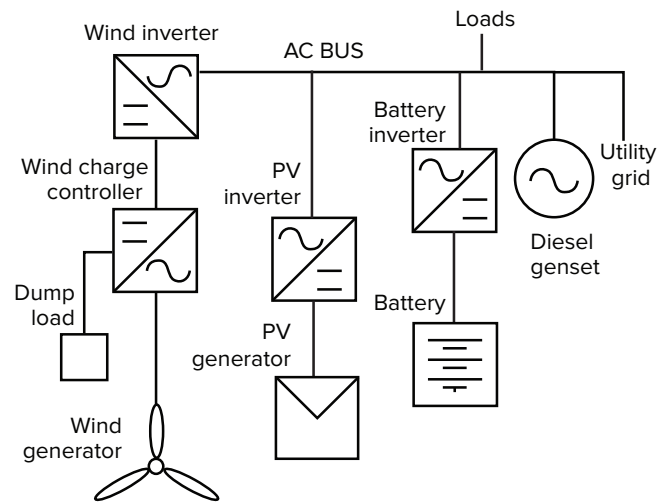
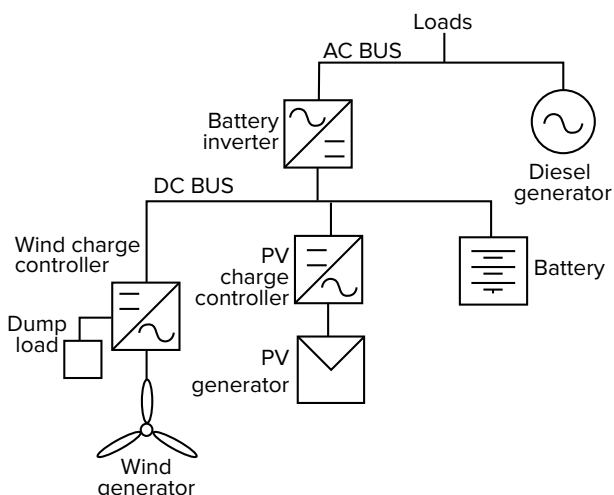
Therefore, it is critical that the battery voltage selection for these systems is of higher voltages (several hundreds of volts); therefore, the maintenance should be done by professionals (not by users, like in small systems) due to the higher hazard risks.

The target configuration detailed in this guideline report will be inverter dominated hybrid systems, usually changing fixed master (bidirectional), with one main diesel generator (there could be two sets of generators in back-up configuration), and with extended (several hours at least) electrochemical storage, either AC or DC coupling.

2.4.4.2.1. Electrical configuration

There are two main types of electrical configurations of hybrid wind-PV plants, depending on how the generators and the battery are coupled: DC-coupling and AC-coupling. In a DC-coupled plant, the generator and the battery are coupled in the DC bus bar through wind or PV charge controllers. In an AC-coupled plant, the generator and the battery are coupled in the AC bus bar through inverters and battery inverters (see Figure 4).

Figure 4. Simple SLDs of a DC-coupled (top) and an AC-coupled (bottom) hybrid plant



When choosing between these two electrical configurations, designers should consider the following:

- Efficiency. Efficiency will be affected by the load profile and the conversion efficiency of the generator inverter, battery inverter, and charge controller. For example, a system powering a load profile with an evening peak might have a higher efficiency with a DC-coupling configuration due to a lower number of conversion steps. However, it must be noted that efficiencies of power conversion equipment are increasing, and efficiency shall be analyzed on a case by case basis depending on the equipment used.

- Cost. As the size of the hybrid plant increases, the AC-coupling configuration will generally become cheaper with respect to the DC-coupling configuration (depending on several factors such as inverter and charge controller type and model, distance from the technical rooms, etc.).

- Electrical safety. Both the generator and the battery in DC-coupling systems can be designed at Extra Low Voltages, offering intrinsic electrical safety. This design may be important in cases where the correct technical skills of the Operation and Maintenance (O&M) personnel cannot be ensured.

- Reliability. In cases where the supply from the grid and the diesel generator is not reliable enough, the reliability of an AC-coupled hybrid plant shall be properly addressed. The inverters are grid-following inverters and can only inject power if there is a grid. The grid can be created by the battery inverter, the diesel generator, or the utility grid. If only the first one is reliable, there might be a blackout if the SoC of the battery is too low, which will make the battery inverter disconnect, and will consequently make the inverters disconnect as well. In this case, the battery will not be able to be charged by the generator unless a proper fallout mechanism is designed beforehand.

A balance between the advantages and disadvantages of the DC-coupling and the AC-coupling can be obtained by using two other coupling configurations: the mixed DC-AC coupling. A mixed DC-AC coupled hybrid plant has both AC-coupled and DC-coupled PV generators, using both inverters and charge controllers.

In AC and DC-AC coupling configurations, designers shall consider the manufacturer limits in terms of the ratio between the PV inverter capacity and the battery inverter capacity.

2.4.4.2.2. Functionalities

The specification of the system's functionalities depends on the project objectives, context, and resources. It is important that the technical specifications clearly define the different modes of operation envisioned and the desired functionalities. The designer shall take into account the following considerations:

- The AC loads can be divided into critical and non-critical loads. By definition, critical loads shall always be powered by the hybrid plant. For example, they might consist of safety lighting loads. In case of low energy available in the hybrid plant, the load shedding of the non-critical loads can be performed in various ways.

For example, the battery inverter can open a contactor through one of its output relays in case of low battery SoC. In the case of high uncertainty in the demand assessment, the load-shedding settings can be fine-tuned during commissioning.

- If the plant features a diesel generator or the grid, a transfer switch will be installed to bypass the hybrid generator and the battery, in case of maintenance, and to continue powering the loads via the diesel generator(s) or the grid.

- The battery inverter should trigger the diesel generator to start on duty when batteries reach a certain DoD. If the facility has more than one diesel generator, it is recommended that the secondary generator(s) starts automatically if the primary generator does not switch on in one minute time. If no generator is able to start, a buzzer alarm should be triggered.

- In systems with more than one diesel generator, the generator on duty should be selected automatically based on a timer with relays (com, NO, NC), which will automatically shift the generator on duty every certain number of hours depending on the number of available generators.

- If the control system disconnects the battery because of an excessive discharge, the system design shall prevent a persistent blackout of the hybrid plant.

- If DC-coupled generators are used, the control system shall be able to restart the power supply the following day when the charge controllers have charged the battery to an acceptable level.

- If there are AC-coupled generators, then they ensure that the batteries can get recharged directly through a diesel generator with a reliable fuel supply. In case there is no diesel generator or that the fuel supply is unreliable, the process that will prevent a persistent black-out shall be clearly specified by the equipment manufacturers involved –

for example, through the configuration of the minimum battery SoC threshold.

- In the case of an unreliable grid supply, the voltage and/or frequency fluctuations are factored in when considering potential battery inverters for the design.
- The design shall consider potential future expansion of the generator capacity, battery capacity, and battery inverter capacity.

2.5. Recommended tools, templates and sources of information

In general, when talking about available hybrid design tools, there are different approaches depending on the following factors:

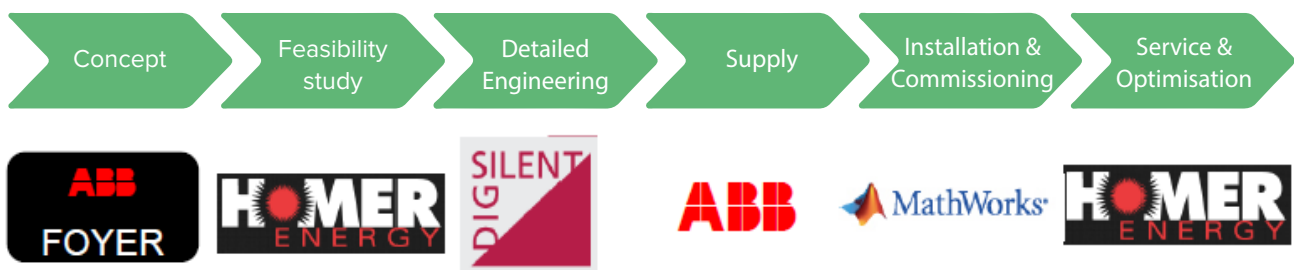
- Level of detail of the design, which is also related to the stage of the design of the project. When there are a few necessary details, such as in the concept design phase, simple spreadsheet-type tools can be used; whereas, dedicated tools are needed for a more detailed analysis, such as in the feasibility study stage. HOMER Pro is an international reference covering most of the levels of detail up to the feasibility study.
- Technologies involved: For example, whereas

diesel power systems are usually designed as a function of maximum and minimum power in the loads, hybrid system designs usually take into account the energy balance for their sizing, thereby covering the power needs.

- Spatial resolution: Centralized hybrid power systems can be designed with a unique profile for each RE resource and load profile (Even if there are distributed loads, the generating system can be designed with a unique load and include the distribution lines.); on the other hand, distributed hybrid systems may require different profiles in the case of long distances. In this case, particular tools may be needed, including Geographical Information System (GIS).

Time resolution: Different configurations of hybrid systems require different time resolution analyses. All of the different configurations require energy balance analysis, which are compiled using minimum monthly and preferably hourly time resolutions, for the optimization design. Furthermore, diesel dominated architectures require dynamic analysis in the case of medium and high percentage RE systems. Examples of tools used for the design of a diesel dominated system with high RE percentage are shown in Figure 5.

Figure 5. Examples of tools used for a high RE penetration hybrid systems in the different design stages.



In the case of the selected configuration for this guideline report, dynamic analysis is not necessary for inverter-dominated systems with one main diesel generator and with extended (several hours at least) electrochemical storage, such as batteries, where battery converters are able to maintain short term stability.

There is a great variety of sizing tools for PV Hybrid systems, but the number is limited when including wind generation in the system. Fortunately, even though the number of tools for PV-Wind hybrid systems design is limited, they are high-quality tools.

According to a comparative study of 68 computer tools for the integration of renewable

was evaluated as one of the most applicable for optimization, feasibility, and sensitivity analysis of both off-grid and grid connected micro-power systems, in addition to being the most used and best known of all the software tools developed so far – in spite of the fact that it has a yearly license fee.

In particular, HOMER Pro has become a standard in the design of hybrid systems, since it merges most of the capabilities for a feasibility study in a single tool, and it also includes wind technology (Other well-known tools for PV systems design, such as PVSYST, do not.); therefore, it is the recommended tool for the configurations detailed in this publication.

03

SPECIFICATIONS FOR TENDER

3.1. Recommendations per component

The sections below present a non-exhaustive list of technical considerations whose level of requirement shall be addressed and adapted by a design engineer based on the project's local context. This information shall be comprehensible and accessible in the technical documentation provided by the bidder.

3.1.1. General

All items within a certain component group (all SWTs, all wind chargers, all PV modules, all PV charge controllers, etc.) should come from the same manufacturer and should have the same models to reduce the complexity of the O&M phase.

Manufacturers shall prove that the components have been used in previous systems with similar functional specifications. Depending on the size of the project and on the procurement requirements, a minimum installed capacity (in previous projects) can be required from manufacturers.

The operational temperatures of the electronic equipment and the batteries shall be specified, depending on the project's location and the

the installation location (indoors with or without air-conditioning or outdoors). For electronic equipment, it is also important to specify the operational humidity conditions.

3.1.2. Wind turbine (WT)

The wind turbine shall comply with the norm IEC 61400-2 Edition 3, Small Wind Turbines, and shall be qualified to and be classified by class according to IEC 61400-12, Annex H, Power Performance Measurements of Electricity Producing Wind Turbines. Wind turbines need to also comply with the requirements of IEC 61400-11 Acoustic Noise Measurement Techniques.

Additionally, the wind turbine model shall guarantee its accreditation through either at least three demonstrable similar installations and/or accreditation of the wind turbine by an accreditation body complying to any of these international standards:

- International - IEC 61400-2: Small Wind Turbines
- United Kingdom - Renewable UK Small Wind Turbine Standard (formerly BWEA Standard)
- United States of America - AWEA Small Wind Turbine Performance and Safety Standard
- Japan - JSWTA Standard

Proof should be required. Moreover, independently measured power curve must be supplied.

In general, it is recommended to use horizontal axis wind turbines, which usually will be a direct drive, i.e., without any gearbox, and with a brushless permanent magnet generator (PMG) – specific to the SWT. For large scale projects, preference remains for horizontal axis wind turbines, with direct drive PMG, or double-fed induction generators and a gearbox.

Although a reference nominal power value is suggested for the SWT, the total annual energy yield is recommended for the general specifications to be met as a more objective specification.

The WT connection box will be installed at the base of the WT tower so they are exposed to the environment; therefore, the box shall at least be IP 65 and UV resistant. The terminals must be clearly marked for the corresponding connections. Connections need to have the screw type with the necessary capacity for the wires. This box must include an emergency button able to stop the WT. The connection of the sensor cables (corresponding to anemometer and wind vane, if present) will also be inside this box.

The WT Interface module will be installed in the technical room. It is required to install type II SPD for all the poles.

3.1.3. Wind Charge Controller

The bidder is required to install a wind charge controller to manage battery charging from the WT. Wind charge controllers should be of the same type as the one used during the approval testing.

A dump load will be used to electronically protect the WT from overspeed (or to limit DC

output voltage). The risk of overheating derived from the dump load during operating periods should be avoided, to lessen the possibility of danger and damage to humans and to minimize fire risks.

There needs to be a manual shutdown button/switch and shutdown procedures (at the connection box at the base of the WT tower). The manual shutdown button/switch shall override the automatic control system and result in a parked machine for all normal operating conditions.

In systems with Li-ion batteries featuring a BMS, it is very important that both the charge controller manufacturer and the battery/BMS manufacturer certify the compatibility of their equipment.

3.1.4. Support structures

Structures should be mounting structures; manufacturers specialized in mounting structures need to be included.

All the mounting structures' material shall be corrosion-resistant, light-weight aluminum, or galvanized steel. The zinc coating should match a specification of 366g/m² with supplier proof or certification.

Special attention must be provided for of electrolytic couples when two different metals are in contact. The stainless steel/aluminum couple is very little corrosive.

If reinforced concrete foundations are used, the concrete should be M25 or C25 grade (with the provision of a cube test as per the relevant EN206-1 code). The C25 grade concrete shall be able to withstand the compressive strength of 25 MPa/mm² on the 28th day after casting. This shall be reported in a test report that includes an identification mark of the specimen, date of the test, age of the specimen, curing conditions, and the manufacturing date of the specimen.

It is recommended that the following items are described in the Engineering Report during the execution phase:

- The calculation tool or software used to size the mounting structure and its foundations
- The standards used for the design of the profiles
- The wind loads considered (for foundation and mounting structure)
- The type of soil, following a soil study
- The dimensions and specifications of the foundations

3.1.4.1. WT structures

The WT support structure, the tower, is recommended to include a tilt-up mechanism so that it can be safely lowered to the ground for maintenance, especially when it is installed in remote site. The WT tower will be as high as possible (height is dependent on the wind speed at the rotor), complying to all the other physical and technical requirements, with a minimum recommended height of 10 meters. Foundation requirements shall be specified by the bidder, including the layout of the foundation, the location of guy wires with minimum and maximum guy location

recommendations, and the guy wire installation requirements if applicable.

3.1.4.2. Solar structures

An ideal compromise for a PV structure is to have the aluminum profiles, aluminum PV clamps, and all the accessories (screws, bolts, fasteners) made of grade 316 stainless steel. The minimum height from ground or roof level to the lowest point of the PV module's frame depends on the amount of snow and vegetation. Roof-mounted structures in locations with strong, snowy seasons are recommended to have a minimum height of 50 cm. Ground-mounted structures in vegetated locations or in locations with strong, snowy seasons are recommended to have a minimum height of 80 cm.

3.1.5. PV modules

It is recommended to use PV modules based on crystalline Silicon (poly- or mono-Si). Mono-Si PERC modules offer better temperature coefficients than poly modules.

PV modules need to comply with the following standards (see Table 3):

Table 3. PV module standards

Code	Name	Notes
IEC 61215-1	Terrestrial PV modules - Design qualification and type approval - Part 1: Test requirements	Lays down requirements for the design qualification of terrestrial PV modules suitable for long-term operation in open-air climates
IEC 61215-2	Terrestrial PV modules - Design qualification and type approval - Part 2: Test procedures	
IEC 61730-1	PV module safety qualification - Part 1: Requirements for construction	Specifies and describes the fundamental construction requirements for PV modules in order to provide safe electrical and mechanical operation
IEC 61730-2	PV module safety qualification - Part 2: Requirements for testing	Provides the testing sequence intended to verify the safety of PV modules whose construction has been assessed by IEC 1-61730

IEC TS 62804	PV modules - Test methods for the detection of potential-induced degradation	Defines procedures to test and evaluate the durability of c-Si PV modules to the effects of short-term high-voltage stress including potential-induced degradation (PID)
IEC 61701	PV modules - Salt mist corrosion testing	Describes test sequences useful to determine the resistance of different PV modules to corrosion from salt mist containing Cl (NaCl, MgCl ₂ , etc.). Only required if the site is in a highly corrosive environment
IEC 62716	PV modules - Ammonia corrosion testing	Describes test sequences useful to determine the resistance of PV modules to ammonia (NH ₃). Only required if the site is in an ammonia-rich environment

Beware of false certificates of conformity to IEC standards (certificates of origin may be required).

In addition, the modules can also be tested through at least one of the following quality and durability programs:

- (PVDI) testing
- Atlas 25+ PV durability testing program
- PVEL's vendor qualification test program
- NREL's Qualification Plus for PV module reliability
- VDE Durability Testing Program
- TUV Sud Thresher or equivalent

All modules shall be equipped with MC4 connectors or equivalent, a UV-resistant junction box with a minimum Ingress Protection rating of IP65, and at least 3 bypass diodes. The PV conductors' cross section shall be at least 4 mm². The terminals shall be clearly marked with + and – for the corresponding connections.

The PV module label should include the following details: Manufacturer name and model, serial number, I_{sc}, V_{oc}, I_{mp}, V_{mp}, P_{mp}, and maximum system voltage.

The PV modules shall have a 10-year minimum product warranty, with a 10% power degradation during the first 10 years and 20 % during a period of 20 years.

The bidder shall provide a flash list containing the results of the I-V test of each module (P_{mp}, V_{oc}, I_{sc}, V_{mp}, I_{mp}). The test shall be carried out under STC conditions with a class-AAA flasher.

Some PV modules feature a black frame and black backsheet (the so-called "full black" modules). They offer an aesthetic advantage, but they have a less efficient thermal behavior compared to conventional modules with an aluminum frame and a white backsheet.

In difficult environments (humidity, saline environment, strong winds, snow loads, hail), the use of double-glass modules is recommended, in view of their better resistance over time to extreme climatic constraints.

3.1.6. PV charge controller

The PV charge controller is one of the most essential components that guarantees a minimum battery lifetime. The characteristics of the charge controller need to be compatible

with the type of battery selected (open lead-acid, sealed lead-acid, Li-ion, etc).

The charge controllers shall comply with the latest version of IEC 62109-1 and/or UL 1741 (see Table 4).

Table 4. PV charge controller standards

Code	Name	Notes
IEC 62109-1	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements	Defines the minimum requirements for the design and manufacture of power conversion equipment for protection against electric shock, energy, fire, mechanical, and other hazards
UL 1741	Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources	Covers requirements for inverters, converters, charge controllers, and interconnection system equipment intended for use in stand-alone (not grid-connected) or interactive (grid-connected) power systems

They shall be on Maximum Power Point Tracking (MPPT) technology and shall have a temperature-compensated charging algorithm. A battery temperature sensor should be supplied, configured, and installed correctly.

The cut-off and alarm levels need to be configured according to the battery SoC.

The operational efficiency must be higher than 97%.

The IP protection should be at least IP20 as per IEC 60529 “Degrees of protection provided by enclosures”, or equivalent, when installed indoors.

Protection must include short-circuits, over-heating, and reverse polarity protections. The product warranty should be equal to or more than five years.

Nowadays manufacturers are designing charge controllers with PV voltages above 150 Vdc. The selection of the maximum PV voltage depends on the operational conditions of the system.

In very remote systems, where O&M personnel have poor technical capabilities, it is recommended to design maximum PV voltages of 150 Vdc so that the DC system stays within the ELV regime. Otherwise, the system can be designed with voltages beyond 150 Vdc, making use of the new generation charge controllers, and possibly reducing the costs.

In systems with Li-ion batteries featuring a BMS, it is very important that both the charge controller manufacturer and the battery/BMS manufacturer certify the compatibility of their equipment.

3.1.7. PV inverter

Nowadays MPPT multi-string PV inverters are gaining market due to their reduced costs, efficiency, and design flexibility. It is recommended to have at least one MPPT per PV inverter, and a maximum of three PV strings per MPPT.

The design engineer will specify the power output of the inverter at the envisioned operational temperature. The manufacturer

should provide proof of this power output via a temperature derating curve (power vs .temperature).

In an AC-coupled system, the design engineer can consider the maximum power of the PV inverters set by the battery inverter manufacturer, in view of the designed battery inverter power.

In unstable grids, it is recommended to design PV inverters that have wide voltage and frequency operational ranges. The configuration of these settings during commissioning is of crucial importance.

PV inverters need to comply with the latest version of the following IEC standards (see Table 5):

Table 5. PV inverter standards

Code	Name	Notes
IEC 62109-1	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements	Defines the minimum requirements for the design and manufacture of power conversion equipment for protection against electric shock, energy, fire, mechanical, and other hazards
IEC 62109-2	Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters	Covers the particular safety requirements relevant to DC to AC inverter products, as well as products that have or perform inverter functions, in addition to other functions, where the inverter is intended for use in PV power systems
IEC 62116	Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures	Provides a test procedure to evaluate the performance of islanding prevention measures used with utility-interconnected PV systems
IEC 61727	Photovoltaic (PV) systems - Characteristics of the utility interface	Applies to utility-interconnected photovoltaic (PV) power systems operating in parallel with the utility and utilizing static (solid-state) non-islanding inverters for the conversion of DC to AC. Lays down requirements for interconnection of PV systems to the utility distribution system

The DC side of the inverters shall include a DC switch that disconnects the positive and negative polarities of each PV string, as well as a Type II SPD as per EN 50539-11. These can be internal or external to the PV inverter.

The nominal frequency should be 50 Hz with a tolerance of ± 5 Hz.

The inverter provides means of controlling

or limiting its power output when required by the power management system, either by responding to the frequency or by an equivalent technique. The Euro-efficiency shall be greater than or equal to 95%. The power factor needs to be adjustable at least between 0.85 and 1, leading and lagging. The IP protection needs to be at least IP65 as per IEC 60529 or equivalent if installed outdoors, and IP20 if installed indoors.

The inverters should be provided with automatic disconnection protection in the event of an insulation fault to earth.

The product warranty needs to be at least five years. Note that some manufacturers can offer longer warranties at an added cost.

3.1.8. Battery inverter

Systems up to 250 kW can be designed with battery inverters with a battery voltage of 48 Vdc. Higher load demands will require inverters with higher power with battery voltages typically in the range of 500-800 Vdc.

The design engineer needs to specify the power output of the inverter at the envisioned operational temperature. The manufacturer should provide proof of this power output via a temperature derating curve (power vs temperature).

The design engineer needs to specify the overload capacity of the inverter, depending on the type of supply loads. Note that motors and compressors may have a high surge power and reactive power requirements.

Battery inverters should comply with the latest version of IEC 62109-1 and IEC 62109-2.

If a three-phase output is required, single-phase inverters can be used to form a three-phase grid through their corresponding communication protocols. In this case, the nominal power assigned to each phase needs to be identical.

Battery inverters should be able to operate in parallel with other battery inverters, PV inverters, BMS, grid, and the diesel generator. The compatibility and communication network of all these components need to be carefully addressed.

Battery inverters (or an external controller) need to be able to automatically start and stop the diesel generator depending on the battery's SoC. When the diesel generator is on, the battery inverters should be able to follow the grid created by the diesel generator.

Deep discharge protection needs to be included. The inverter should stop any operation other than recharging if the battery voltage or the SoC is below the minimum permissible threshold.

Overcharge protection should be included. Inverter needs to stop any recharging operation if the voltage of any battery cell is higher than the maximum permissible voltage.

The maximum Total Harmonic Distortion (THD) should not exceed 5%.

Cut-off and alarm levels need to be configurable according to the battery SoC.

The maximum efficiency should be equal to or higher than 95 %. Depending on the load profile and the sizing of the battery inverter, the design engineer may need to require the efficiency at several power points to the manufacturer (e.g. at 5%, 20%, 50% and 100% of the nominal continuous power output at 25°C).

If installed indoors, the IP rating shall be at least IP20 as per IEC 60529.

The product warranty needs to be at least five years. Note that some manufacturers can offer longer warranties with an added cost.

When using Li-ion batteries with a BMS, the manufacturer of the battery/BMS and the manufacturer of the battery inverter should certify the compatibility of their equipment.

3.1.9. Li-ion battery and BMS

In very remote systems where O&M personnel have poor technical capabilities and with battery inverters below 220 kW, it is recommended to

design a battery voltage at 48 Vdc so that the battery side stays within the ELV regime. The battery needs to comply with the latest version of the following standards (see Table 6):

Table 6. Li-ion battery standards

Code	Name	Notes
UN38.3	Transport of dangerous goods	Specify test methods and requirements for lithium batteries to ensure their safety during transport
IEC 62281	Safety of primary and secondary lithium cells and batteries during transport	
IEC 62619	Secondary cells and batteries containing alkaline or other non-acid electrolytes-Safety requirements for secondary lithium cells and batteries, for use in industrial applications	Specifies requirements and tests for the safe operation of secondary lithium cells and batteries used in industrial applications, including stationary application

In high-temperature locations, it is recommended to use Lithium Iron Phosphate (LFP) batteries in view of their better thermal stability.

At a DoD of 85%, the number of cycles shall be equal to or higher than 3000 at a 20°C temperature and a charging/discharging rate of 0.25C.

The self-discharge shall not exceed 4% per month at a 20°C temperature.

Each battery polarity should be protected by an overcurrent protection device for paralleling the batteries on the common DC bus.

Any bare live parts need to be properly insulated.

The product warranty should be at least two years. Note that manufacturers may quickly improve their warranty conditions in the coming years, and this specification shall be revisited. The BMS should meet or exceed the following technical specifications:

- Control and balance of each individual battery cell
- Management of charge and discharge of each battery
- Protection against over-charging, under charging, over-heating, and overload
- Integration into the power plant’s control and monitoring system
- Measure, record, and report the following parameters
 - SoC and SoH
 - Voltage
 - Charge/discharge current
 - Temperature

3.1.10. Control and monitoring

The control and monitoring system shall provide the following minimum functionalities:

- Battery monitoring, to evaluate the state of charge (SoC) using a calculation algorithm that considers the following parameters:
 - Initial capacity
 - Measurement of incoming and outgoing current and the associated charge/discharge rate

- Battery efficiency
- Aging
- Voltage
- Temperature
- Self-discharge
- Battery technology

- Data acquisition system
 - Real-time information on the status of the system
 - Historical energy production and consumption data
 - Recording of events and faults
 - Assistance to the system's O&M operator
 - Troubleshooting

- Measured and stored parameters
 - Wind generator and/or wind charge controller current/voltage
 - PV generator and/or PV charge controller current/voltage
 - Grid current/voltage
 - PV inverter AC current/voltage
 - Battery inverter AC current/voltage
 - Battery voltage
 - Diesel generator current/voltage
 - Solar irradiation, PV module temperature, battery and technical room temperature

Measured or calculated information, available on site

- Daily energy supplied by the wind generator and/or wind charge controller
- Daily energy supplied by the PV generator and/or PV charge controller
- Daily energy consumed by the grid and the internal loads
- Daily energy supplied by the PV inverter
- Daily energy supplied by the diesel generator
- Daily energy supplied by the battery inverter (in both directions: charging and discharging)
- Performance ratio

Remote monitoring is recommended, as long as the minimum parameters are displayed on site via screens and as long as there is a team

that has the ability and time to process and analyze all the data that such a system can deliver. When considering remote monitoring, the reliability of data telecom networks and the payment of internet subscriptions need to be ensured.

3.2. Documentation

3.2.1. Bidding phase

It is recommended that bidders provide the following technical information in their bid:

- Design Report, which describes the engineering of the proposed solution (functionality, capacity, inter-connections), demonstrating that it meets or exceeds the project requirements

- Set of drawings, including:

- Layout of the wind and PV generators, showing the location of the main components on the site
- SWT and PV support structure, including foundations
- Plan of the technical room, showing the installation of the battery and other electronic and auxiliary equipment
- Single line diagram of the entire installation and its integration into the existing infrastructure.

- Supporting documents per component including:

- Datasheets
- Certifications
- Factory acceptance test reports
- Installation and operation manuals
- Warranty certificates

- Construction plan including

- Implementation plan for the works on site (risk management; quality assurance and quality control measures; health, safety, and environmental (HSE) safeguards; quality control measures)
- Equipment to be provided

- Detailed program schedule, covering all relevant milestones during all project phases
- Training plan (if any)
- O&M plan (if any), including a description of routine activities and required personnel/equipment, spare parts and response strategies.

3.2.2. Engineering phase

Once the contract has been awarded and during the detailed engineering phase, the contractor shall provide the Detailed Engineering Design Report. This report should include all necessary drawings and design calculations covering all the main components of the power plant. At least the following documents shall be included:

- Civil engineering drawings, including at least:
 - SWT tower drawings, including all the necessary details for the proper installation, including the tower foundations.
 - PV structure drawings, including all the necessary details for the proper installation of the PV structure foundations or the integration into the roof
 - Technical room drawings
 - Specifications of other civil works required by the project
- Installation drawings, showing the details of the installation of the diesel generator and all equipment inside the technical room, including at least the power conversion equipment, battery, switchboards, cable trays, and internal electrical distribution
- Detailed electrical drawings including at least:
 - General SLD
 - Earthing diagram
 - Physical diagram of the wind turbine
 - Physical diagram of the PV strings

- Detailed diagram of the battery inverter connections
- Detailed diagrams of all the switchboards
- Detailed diagram of the connections of the inverters
- Detailed diagram of the connections of the battery
- Detailed diagram of the connections of the charge controllers
- Detailed diagram of the connections of the diesel generator
- The diagram of the distribution of internal loads
- Structural calculation note for the mounting structures
- Shading losses calculations due to obstacles, both for solar and wind
- Cable sizing calculations
- Protection sizing calculations
- The expected performance specifications
- Details of procedures during construction works
- Details of the equipment testing and testing procedures
- Details of the plant commissioning test procedures
- The complete manufacturer's documentation of the main components (wind turbine, tower, wind charge controller, PV modules, PV mounting structure, PV charge controllers, PV inverters, battery inverters, battery, diesel generator, monitoring system).

04

INSTALLATION AND COMMISSIONING

4.1. Installation best practices

4.1.1. General

In order to limit the risks during the installation and commissioning phases, the following general safety measures are recommended at the worker level:

- Electrical installers shall have at least a basic education in general electricity (equivalent to the French “Baccalauréat professionnel” or “Technicien Supérieur” levels).
- Supervisors need to have specific experience in PV hybrid power plants.
- If applicable, workers should be trained in working at heights.
- The team must include at least one person trained in First Aid.

Before leaving for the site, the installation team shall:

- Have all the technical documents necessary for installation, including the manufacturers’ user manuals, technical execution files and drawings, control and acceptance sheets, configuration software.
- Make a detailed list of all installation components and accessories.
- Check that the components have been delivered without damage.

- Check that all the installation instructions prescribed by the supplier are understandable and feasible (in a language understood by the installers).
- Ensure the provision of personal protective equipment and safety equipment (helmets, clothing, insulating gloves, safety shoes, face shield, non-contact voltage testers, insulating tools, etc).

4.1.2. Common considerations for generators location selection

When selecting a location for the wind and the PV generator, the following should be considered:

- Agreement with local authorities or local community, ensuring no conflicts over land
- Soil characteristics. For example, rocky or stony soil can pose challenges during installation.
- If it is essential to clear the site from surrounding trees that can provide shade, ensure that all environmental and social protocols are followed.
- Risk of shading
- Risk of theft
- Risk of intentional and unintentional damage
- Risk of gulying, rainwater management
- Accessibility for the O&M staff

- Proximity to the technical room where the power conversion equipment and batteries are installed.

On the other hand, there are other considerations that are technology dependent, which will be described in the following sections.

4.1.3. Wind turbine

Although some guidelines will be given here, the experienced installer will have to be the one who has the knowledge of how to act in the different situations that arise in each installation and in each of the parts that make it up.

For a complete study, the foundations have to be calculated for the wind turbine installation.

An important aspect is that if the prevailing wind direction is known in advance, the anchoring system should be best done in that direction because it is the most critical one.

For the lifting and/or lowering of folding towers, a number of recommendations must be followed:

- When lowering a tower, it is important to leave the structure resting on some kind of support prepared in advance so that it can support the weight of the complete tower. The point where it should be placed and the height of the support point will often depend on the terrain; but in normal conditions it will be placed at about $\frac{3}{4}$ of the maximum height of the tower; and it should be at a height where the wind turbine can be operated without problems and where no part of the wind turbine can suffer any mishap during the lowering and/or lifting.

Figure 6. Example of support structure for resting the SWT when lowered (Source: Small Wind Guidebook - WINDEXchange).



- To carry out the lifting and/or lowering process, it is necessary to place a winch at the base of one of the guy ropes (the one that the pulley points to), and a series of pulleys placed between this winch and the anchoring point with the tower, to reduce the force with which it has to be pulled.
- The guy rods must be tightened as the wind turbine rises, to keep it aligned with the pole and so that neither the bolts nor the guy rods themselves suffer and break. They should not be excessively tensioned, since this tension will have repercussions on the anchoring points with the tower – where a lot of effort will be exerted corresponding to the stress on the material.
- The guy ropes should be as well positioned as possible. In other words, the tension forces should be distributed as evenly as possible. For example, if the guy ropes are to be placed in four directions, place them at 90° , and as accurately as possible, almost to the centimeter.
- In the case of installation on a slope, the positioning of the anchoring points and the guide pole should be done in a way where the tower is supported in the upward direction of the ramp when it is lowered.

- It is very important before mounting the wind turbine to lower and raise the tower just to calculate the wind distances and to be able to leave them quite taut, so that later when the tower is raised with the wind turbine in place there are no problems.

4.1.4. PV generator

When selecting a location for the PV generator, the following should be considered:

- Agreement with local authorities or local community, ensuring there are no conflicts over land.
- Soil characteristics. For example, rocky or stony soil can pose challenges during installation.
- If it is essential to clear the site from surrounding trees that can provide shade, ensure that all environmental and social protocols are followed.
- Risk of shading
- Risk of theft
- Risk of intentional and unintentional damage
- Risk of gulying, rainwater management
- Accessibility for the O&M staff
- Proximity to the technical room where the power conversion equipment and batteries are installed.

The orientation and tilt must be justified in relation to the seasonality of the load demand and the climatic conditions (irradiance and temperature). The use of specialized PV software is recommended to find the orientation and tilt that best suits the project's requirements. On the other hand, the tilt must be at least 10°, so as to ease the self-cleaning of the PV modules with rainwater.

The following are recommendations for ground-mounted PV generators:

- If the terrain is in a vegetated area, the height of the bottom-most part of the PV generator needs to be at least 80 cm in order to limit the risk of shading.

- The terrain should be as flat as possible to limit the need for earthworks and the management of rainwater run-off.

- Sufficient spacing between PV strings needs to be ensured to limit row-to-row shading losses and allow the passage of the O&M personnel.

- Security fencing might be required depending on the security conditions of the site. The shading losses created by the fence need to be minimized.

- Near or far shades onto the PV generator need to be prevented at least between 8am and 4pm (solar time).

The following are recommendations for roof-mounted structures (flat or tilted):

- The installation of a PV generator on the roof will easily generate a static overload of 15 to 20 kg/m² (excluding ballast) and can modify the wind resistance of the building. Prior approval from a structural engineer is essential.

- It is recommended to leave a 1-meter-wide corridor around the PV generator.

- Near or far shades onto the PV generator need to be prevented at least between 8am and 4pm (solar time).

- When installed on flat roofs, the PV rows shall be spaced sufficiently far apart to limit cast shadows and allow for the passage of a person.

- When installed on tilted roofs, it is essential to contact manufacturers and building constructors to find out the compatibility between the fixing system and the roof elements, considering the following items: roof sheet thickness, type of lacquering, center-to-center distance between the purlins, compatibility of the fixing pieces.

Also, a sufficient air gap underneath the PV modules of at least five centimeters needs to be left in order to ensure proper ventilation.

- A careful analysis of the roof waterproofing needs to be conducted before choosing the right location for the PV generator installation.

PV modules usually have a tempered glass at the front and are therefore fragile. They should be transported with care, keeping the original packaging, and should be handled carefully on site to prevent them from being knocked over.

PV connectors need to be from the same manufacturer and model.

A minimum clearance of 0.25 in (6.5 mm) or more between modules is required to allow for thermal expansion of the frames.

Never drill holes in the module frames. Always use the holes provided for this purpose.

Never step on the modules: Although the glass does not break, this causes invisible micro-cracks in the cells which will decrease their performance after few years.

The following list provides precautions during the installation of the PV generator cables:

- Lay the cables in a way where there is no risk of a short circuit between the positive and negative polarities (Use unipolar double-insulated PV cables (PV1-F marking).
- Respect the permissible bending radius of the cable.
- Cables should not be left in the water for long periods of time.
- The cables should not obstruct the drainage of rainwater or be a source of dust accumulation.
- Only use black UV-resistant cable ties to attach cables outdoors.
- Avoid abrasive edges.
- The length of the PV string cables need to be as short as possible.
- Lay the cables in a way where they are protected from rodents and pets, as well as out of the reach from children or animals (Use UV-resistant cable conduit if exposed to sunlight).

- Mark the cables to identify them and indicate their polarity.
- The passage of cables through roofs or walls must be made through a suitable pipe maintaining the waterproofing.
- Unipolar (+) and (-) cables and the earthing conductor must be joined along their entire route to avoid induction loops that could lead to destructive over-voltages in the event of lightning strikes.

4.1.5. Equipment installed below the PV generator

Certain equipment can be installed below the PV modules, as long as the following principles are respected:

- PV charge controllers, PV inverters, and all electrical boards shall have a minimum IP rating of IP44, ideally IP54 or IP65.
- All equipment must be protected from direct sunlight (especially the enclosures of the electrical boards, which are often made of PVC), both to mechanically protect the equipment and to avoid overheating.
- Parts of the system that are inevitably exposed to direct radiation (e.g. cable ducts and cable trays) should be made of materials specifically designed for outdoor use (e.g. galvanized steel cable tray).
- All support frames shall be made from non-corrosive materials: Galvanized steel, ideally aluminum or stainless steel.
- All fixing nuts and bolts need be made from galvanized steel, ideally stainless steel (beware of electrolytic couples between metals of different types in corrosive environments).
- Ideally, and if the terrain permits, the diesel generator should be installed at a distance of at least 10 meters from the PV generator,

sheltered from prevailing winds, and protected against direct sunlight and rain.

- The site should have reliable security fencing, permanent guarding, and lighting.

4.1.6. Technical room

The technical room(s) usually hosts the power conversion equipment (battery inverters, PV charge controllers), the batteries, switchgear, as well as monitoring and control equipment. Depending on the battery type, two rooms might be needed, one for the batteries and another for the electronic equipment.

It is important that the room is located as close as possible to the PV generator (without causing considerable shading losses) within the fenced area of the facility, and that it is illuminated by one or more security lights on site.

The following list provides some principles when designing the technical room:

- If using open lead-acid batteries, the battery room must be completely separated from the electrical room (risk of corrosion and explosion due to the release of acid fumes). If the battery has as voltage above 120 Vdc:
 - The electrical design and component selection need to ensure that all enclosures containing live conductors comply with Class II and IP2X index.
 - The access to the battery room should be limited to trained and authorized personnel (signs on the entrance door, lockable room with a key) and should require the wearing of personal protective equipment (insulating gloves, face visor) for any intervention.
- The room (or shelter) of the diesel generator should be specific and structurally separated from the general room to limit the transmission of vibrations.

- The dimensions of the rooms shall take into account:

- dimensions of entire ensemble of components
- manufacturers' installation rules
- the movement of people under minimum safety conditions.

- The room should be airtight and watertight even under heavy rain. Rainwater management strategies need to be considered.

- Management of openings:

- Metal or PVC main access door with key locking system
- Internal doors should not be key-lockable, allowing an easy access to emergency disconnection elements
- Windows installed on walls should not be exposed to the prevailing wind(s)
- Protection against the rain (brise-soleil type) needs to be provided above the windows.

- Ventilation and thermal management:

- Beware of the energy demand of air-conditioning units. Depending on the location and the battery type, air-conditioning units can be avoided via a proper bioclimatic design of the room; for example, avoid battery rooms with west facing walls, include a naturally ventilated space between the ceiling and the roof, and ensure that no direct sunlight enters the battery room. The desired room temperature should consider the warranty terms and conditions of the battery manufacturer. Consult the manufacturer in case of doubt.
- Do not install critical components such as batteries or electronic equipment on west-facing façades.
- When using open lead-acid batteries, the battery room should have high and low ventilation openings protected from rainwater. The calculation of the surface areas will depend on the wind conditions, the volume of the room and the air renewal rate required by the battery manufacturer, in accordance with the requirements of IEC 62485-2.

- Interior electrical distribution:
 - The technical room should be permanently supplied by the hybrid power plant via a network that is independent of the main grid. This can be done via a dedicated feeder in the main distribution board, or by installing a safety stand-alone inverter on the battery that specifically supplies the technical room.
 - Each room should have low-consumption lights and a network of electrical sockets.
 - The switch for the battery room lighting must be located outside the battery room in case of open lead-acid batteries.
 - One or more outdoor lighting points are recommended.

- Annex room for the diesel generator :
 - Room or shelter dimensions should consider the size of the diesel generator and at least 1 m around the generator for the safe passage of O&M personnel.
 - Consider the integration of accessories: Small tank, electrical cabinets, exhaust silencer, starter battery.
 - Reservations need to be made for electrical and control connections to the technical room, air inlets, hot air exhaust, combustion fumes exhaust, channels for oil, and fuel leakage management.
 - Design of the room should prevent the fumes from being transported to the technical room or the PV generator through the prevailing winds.
 - Additional storage rooms or shelters need to be provided for the safe and clean storage of fuel and lubricants, as well as spare parts.
 - In the case of an enclosed room, natural ventilation openings must be provided to ensure the supply of fresh air for the engine and the evacuation of heat.

4.1.7. Equipment installed inside the technical room

The manufacturer installation instructions need to be carefully respected at all times. Moreover, in light of the high temperatures that can be

recorded in the Lebanese desert, it is recommended to increase the recommended spacings between equipment, in order to minimize equipment overheating and maximize their lifetime.

Components should be ideally fixed at a height between 1.50 and 1.80 m.

Unauthorized personnel need to be prevented from accessing critical components.

Labels need to be clear, easily visible, and fixed in order to remain legible and in place throughout the design life of the power plant.

4.1.8. Labelling

The main equipment, cables, and fittings of the installation must be identified and marked with labels that are easily visible and permanently fixed in accordance with the plans and diagrams of the installation.

- Combiner boxes
- DC and AC cables
- Inverters, charge controllers, and battery inverters
- Protective devices and switchgear
- Any emergency disconnection devices

Consider the safety of all the various stakeholders involved (maintenance managers, inspectors, public distribution network operators, emergency services, etc.); it is essential to indicate the presence of a PV installation on a building.



CAUTION:
Live DC cables

A label stating:

“Caution: Live DC cables” :

- On the front side of the combiner boxes
- On the front side of the DC boxes
- On both ends of the DC cabling, at least
- On the front side of the charge controllers

Generator

For circuits with an open circuit voltage greater than 60 V, the presence of dangerous voltage must be indicated on the following components:

- Combiner boxes
- Cable routes
- Charge controller

The marking must be visible and unalterable, indicating that active parts inside these boxes or cable routes remain live during the day even after disconnection of the charge controller or inverter on the DC side.



A label stating “Do not maneuver under load” near the plug-in fuse-disconnectors and SPDs



A label with the words “Do not disconnect under load” or the label shown below, should be located near the visible and accessible DC connectors, which do not have the corresponding marking.

Battery

The access door to the battery room and the battery support shall be marked with:

- Smoking ban
- The danger of explosion
- The risk of acid burns (in the case of lead-acid batteries)
- The risk of electric shocks (if nominal battery voltage > 60 V)
- Access prohibited except to authorized personnel

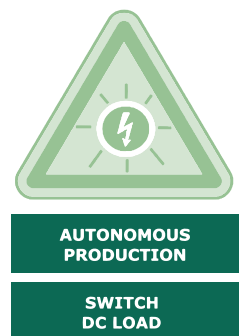


All conversion equipment that can be powered from more than one source need to be marked to indicate that all voltage sources (DC and AC) must be isolated before any work is carried out on this equipment.



Switching off DC and AC loads

A warning label shall be located close to the general DC switchgear and the general AC switchgear.



Display

It is recommended to laminate the following documents and display them in the technical room:

- Single Line Diagram
- Operating instructions
- Emergency shutdown procedure(s)

4.2. Commissioning best practices

The commissioning of a power plant consists of an installation inspection followed by tests and measurements. It aims at verifying the safe and proper operation of the system. It should be performed as soon as the plant installation is completed and before switching on the system for the first time.

4.2.1. Inspection

The installation inspection confirms that the installation is complete before taking any measurements. It involves the following checks:

- Confirm that the system complies with the

Detailed Engineering Design Report, previously approved by the employer.

- Confirm that all structural and electrical components are properly mounted, wired, and secured.
- Confirm that the components are neatly installed and there is proper wire management.
- Confirm proper connections, terminations, and terminal torque specifications.
- Confirm that all system and equipment markings and labels are correct and in the right place.
- Confirm that all equipment settings/adjustments are set properly.
- Confirm the correct grounding of the equipment.
- Confirm that all switching devices are open and fuses are removed.
- Conduct a site clean-up.

4.2.2. Measurements

The staff involved in the measurements can be divided into three levels (see Table 7):

Table 7. The three different levels for technicians

LEVEL 1	A LEVEL 1 technician is an electrician working on the construction site, with field experience in the installation of wind-PV hybrid power plants, but only performs tasks with the support of a LEVEL 2 or LEVEL 3 technician. A LEVEL 1 technician may be involved in inspection and technical acceptance tasks supporting a LEVEL 2 or LEVEL 3 technician. He/she does not take initiatives on the electrical and functional aspects of the works
LEVEL 2	A LEVEL 2 technician is an experienced electrician (university level or sub-university level with solid experience) with additional training in wind-PV hybrid power plants (minimum 10 days, including five days of tutorial and hands-on tasks). He/she is certified in the installation and inspection of wind-PV hybrid power plants and has a good understanding of the operation of the different components (wind turbines, PV modules, diesel generator, power conversion electronics), the usage of measuring equipment, and personal protective equipment. This technician is authorized to carry out most of the acceptance tests under the supervision of a LEVEL 3 technician

LEVEL 3

A LEVEL 3 technician is a specialist in general electricity and wind and photovoltaic technology (engineer or senior technician with solid field experience), with several years of experience in the design, construction, supervision, and operation of wind-PV hybrid power plants. He/she is certified in the installation and inspection of wind-PV hybrid power plants. He/she is responsible for supervising all the on-site verifications and measurements and is solely responsible for verifying the completeness of the as-built reports and O&M manuals. He/she needs to have a proven understanding of the operation of the components and the behavior of the generators and batteries under different conditions in order to detect possible hidden failures. In addition, he/she must be trained by the manufacturers in the manufacturer-specific settings of inverters, diesel generators, battery inverters, and charge controllers

4.2.2.1. No-load measurements

Table 8 shows the minimum measurements to be carried out on the wind turbine:

Table 8. No-load measurements – wind turbine

Measurement	Equipment	Safety risks	Protective measures	Qualifications of the technician
No-load voltage and frequency (according to manufacturer's datasheet)	Network analyzer	Electric shock wind turbine overspeed	Insulating gloves	Level 2
Normal vibration and noise level	Human perception	Wind turbine overspeed	Not applicable	Level 2

Table 9 shows the minimum measurements to be carried out on the PV generator:

Table 9. No-load measurements – PV generator

Measurement	Equipment	Safety risks	Protective measures	Qualifications of the technician
Voc oh each PV string (tolerance of +/- 5% between each string connected in parallel)	Multimeter	Electric shock above 120V, electric arc	Face visor and insulating gloves	Level 2
Power analysis (curve $I=f(U)$) on a sample of 10% of the PV field (directly on approx. 10% of the PV strings) and measurement of the short-circuit current I_{sc}	IV tracer	Electric shock above 120V, electric arc, short circuit during measurement	Insulating gloves	Level 3

Insulation check on each PV string (between 10 and 30 MOhms)	Insulation monitoring device	Electric shock above 120V	Face visor and insulating gloves	Level 2
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Table 10 shows the minimum measurements to be carried out on the diesel generator:

Table 10. No-load measurements – diesel generator

Measurement	Equipment	Safety risks	Protective measures	Qualifications of the technician
No-load voltage and frequency (according to manufacturer's datasheet)	Network analyzer	Electric shock	Insulating gloves	Level 2
Engine speed (temperature, no-load consumption)	Screen of the generator	Burn	Thermal gloves	Level 2
Normal vibration and noise level	Human perception	Not applicable	Not applicable	Level 2

Table 11 shows the minimum measurements to be carried out on the battery:

Table 11. No-load measurements – battery

Measurement	Equipment	Safety risks	Protective measures	Qualifications of the technician
Cell voltage at rest before formatting (for lead-acid batteries)	Multimeter	Arcing, explosion, in case of accidental short circuiting	Face visor	Level 2
Cell voltage at rest after formatting (for lead-acid batteries)	Multimeter	Arcing, explosion, in case of accidental short circuiting	Face visor	Level 2
Voltage of batteries connected in parallel (disconnect from each other) after formatting, tolerance of +/- 3% (for lead-acid batteries)	Multimeter	Electric arc, explosion, in case of accidental short circuit. Electrocutation if the DC bus voltage is higher than 120 V	Face visor and insulating gloves	Level 2

Density measurements) on 10% of the cells (for open lead-acid batteries)	Densimeter	Burn due to acid splash	Protective goggles and gloves, suitable clothing	Level 2
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Table 12 shows the minimum measurements corresponding to the equipotentiality and earthing of the system:

Table 12. No-load measurements – Earthing

Measurement	Equipment	Safety risks	Protective measures	Qualifications of the technician
Electrical continuity between all metal masses	Ohmmeter	Not applicable	Not applicable	Level 2
Value of the resistance to earth	Specific device	Not applicable	Not applicable	Level 2

Table 13 shows the minimum checks corresponding to the configuration of the power plant:

Table 13. Configuration of the power plant

Measurement	Qualifications of the technician
WT converter configuration compatible with battery inverter and diesel generator	Level 3
PV inverter configuration compatible with battery inverter and diesel generator	
Battery technology and capacity correctly configured	
Threshold for the alarm or for the automatic start-up of the diesel generator when battery in low SoC condition	
Restart threshold after power plant interruption	
Battery charging thresholds (for lead-acid batteries): Bulk, absorption, floating	
Threshold and automation of the equalization charging for open lead-acid batteries	
Configuration of the DC measurement shunts if required	

Configuration of the compensation of the battery regulation depending on the temperature, if required	Level 3
Communication of the monitoring system with all components	
Possible controls via relays: Activation of alarms, cooling systems, load shedding, diesel generator start, shut-down, etc	

4.2.2.2. Measurements under load

Table 14 shows the minimum measurements to be carried out on the wind turbine:

Table 14. Measurements under load – Wind Turbine

Measurements (meas. conditions: windy day, distribution line load $\geq 20\%$ of the nominal load of the power plant)	Equipment	Safety risks	Protective measures	Qualifications of the technician
Wind speed, voltage, and current (output power) at the output of the wind charge controller, at different times	Anemometer, multimeter	Not applicable	Insulating gloves and face visor	Level 2
Proper operation of manual switching devices under load	Manual test	Failure of a switching device - arcing	Insulating gloves and face visor	Level 1
Dump load test: With the battery at high SoC, disconnect the demand and allow the battery voltage to increase so that the dump load starts functioning	Manual test	High temperatures. Fire risk	Insulating gloves and face visor	Level 3

Table 15 shows the minimum measurements to be carried out on the PV generator:

Table 15. Measurements under load – PV generator

Measurements (meas. conditions: windy day, distribution line load $\geq 20\%$ of the nominal load of the power plant)	Equipment	Safety risks	Protective measures	Qualifications of the technician
Pmpp, Voc, Vmpp, Isc, Impp of each PV string, as well as of the overall output of the PV generator (tolerance of +/-5%) - this measurement should be made by disconnecting the PV strings from the system (open circuit)	IV tracer or similar	Not applicable	Not applicable	Level 2
Proper operation of manual switching devices under load	Manual test	Failure of a switching device - arcing	Insulating gloves and face visor	Level 1
Output power of each PV string	Manual test or reading from console	Electric arc (if manual test)	Insulating gloves and face visor	Level 1

Table 16 shows the minimum measurements to be carried out on the diesel generator:

Table 16. Measurements under load – diesel generator

Measurements (meas. conditions: sunny day, distribution line load $\geq 20\%$ of the nominal load of the power plant)	Equipment	Safety risks	Protective measures	Qualifications of the technician
Frequency variation as a function of the load (check of the droop curve)	Network analyzer	Not applicable	Not applicable	Level 1
Stable operation in WT+PV+Genset+Battery mode	Observation	Not applicable	Not applicable	Level 1
Stable operation in genset+battery mode	Observation	Not applicable	Not applicable	Level 1
Stable operation in genset-only mode	Observation	Not applicable	Not applicable	Level 1

Proper operation of manual switching devices under load	Manual test	Not applicable	Not applicable	Level 1
Measurement of the specific fuel consumption as a function of the load	Liquid measuring equipment	Fuel splash, burns	Thermal gloves, safety glasses	Level 1
Measurement of the specific engine-oil consumption as a function of the load	Liquid measuring equipment	Not applicable	Thermal gloves, safety glasses	Level 1

Table 17 shows the minimum measurements to be carried out on the battery:

Table 17. Measurements under load – battery

Measurements (meas. conditions: sunny day, distribution line load $\geq 20\%$ of the nominal load of the power plant))	Equipment	Safety risks	Protective measures	Qualifications of the technician
Homogeneous battery charging currents between batteries connected in parallel	Current clamp meter	Not applicable	Not applicable	Level 2
Homogeneous battery discharge currents between batteries connected in parallel	Current clamp meter	Not applicable	Not applicable	Level 2
Operation of manual switching devices under load	Manual test	Failure of a switching device, arcing	Insulating gloves and face visor	Level 2
Measurement of battery voltages at different states of charge (for lead-acid batteries): Bulk, absorption, floating, etc	Multimeter	Arcing, explosion, in case of accidental short circuit	Insulating gloves and face visor	Level 2
Test of the activation of the battery management control relays according to the battery state of charge	Observation	Not applicable	Not applicable	Level 3
Low battery voltage switch-off test	Observation	Not applicable	Not applicable	Level 3

Table 18 shows the minimum tests corresponding to the monitoring:

Table 18 Measurements under load – monitoring

Measurements (meas. conditions: sunny day, distribution line load $\geq 20\%$ of the nominal load of the power plant)	Equipment	Safety risks	Protective measures	Qualifications of the technician
Analysis of the values recorded over 24 hours of operation	Observation	Not applicable	Not applicable	Level 3
Check of the communication with the remote monitoring platform, if necessary	Observation	Not applicable	Not applicable	Level 3
Consistency between the dynamic display of parameters and the measured values (currents, voltages, powers, etc.)	Observation	Not applicable	Not applicable	Level 3

Table 19 shows the minimum tests to be carried out on the Main AC board:

Table 19 Measurements under load – Main AC board

Measurements (meas. conditions: sunny day, distribution line load $\geq 20\%$ of the nominal load of the power plant)	Equipment	Safety risks	Protective measures	Qualifications of the technician
Test of all the circuit breakers, switching devices and transfer switches of the Main AC board	Manual test	Failure of a switching device - arcing	Insulating gloves and face visor	Level 2

Table 20 shows the minimum measurements to be carried out on the main components:

Table 20 Measurements under load – power conversion equipment

Measurements (meas. conditions: sunny day, distribution line load $\geq 20\%$ of the nominal load of the power plant)	Equipment	Safety risks	Protective measures	Qualifications of the technician
Wind/PV inverter(s): Display ok, efficiency measurement, no faults	Observation	Not applicable	Not applicable	Level 3
Wind/PV charge controller(s): display ok, efficiency measurement, no faults	Observation	Not applicable	Not applicable	Level 3
Battery inverter(s): display ok, efficiency measurement, no faults	Observation	Not applicable	Not applicable	Level 3

4.2.3. Hand-over documents

The hand-over documents to be provided by the contractor include:

- As-built report
- O&M documents
- Equipment warranty documents

The as-built report needs to be provided by the contractor 30 days after commissioning. It should contain (at least) the following documents:

- All the executive drawings and diagrams:
 - Single line diagram
 - Detailed multi-wire diagram
 - Earthing and equipotential bonding diagram
 - Communication bus wiring diagram
 - Wiring diagram for DC and AC boards and cabinets
 - Technical room's implementation drawing
 - Component's installation layout drawing
 - Foundations drawing (technical room and mounting structures, if applicable)
 - Earthing drawing plan of the entire site

- Set of calculation notes:

- Calculation of the wind and PV generator's energy yield
- Calculate the compatibility of the current, voltage, and power between the wind/PV generator and the component(s) that are connected to it.
- Calculation of the compatibility between the diesel generator droop curve and the power/frequency curve of the inverters (for AC-coupled or mixed DC-AC coupling configuration)
- DC cable sizing: Current carrying capacity and voltage drop
- AC cable sizing: Current carrying capacity and voltage drop
- Sizing of protection and switching devices on the generator side
- Sizing of protection and switching devices on the battery side
- Sizing of protection and switching devices on the AC side

- Soil study and dimensioning of the foundations (technical room, mounting structure)
- Calculation of wind load for structures
- Calculation of the temperature of the technical room taking into account the cooling measures implemented: Natural ventilation, forced mechanical ventilation, air conditioning, etc.

- Ensemble of all the components' data sheets, manuals, and certificates.

- Initial configuration settings of the power plant:

- Protection modes of the battery (voltage and current thresholds, SoC, temperature thresholds, etc).
- For lead-acid batteries: Charging voltage thresholds (bulk, absorption, floating, and equalization for open lead-acid batteries).
- Type of diesel generator control.
- List of all deviations from the "factory settings" of the components: charge controller, generator inverter, battery inverter, and associated control accessories.

- Specific notes (non-exhaustive, must be adapted to each context) on the following:

- Rainwater management of the technical room/building and in gullies near the mounting structures.

- Ventilation management of the technical room(s)
- Site security (fencing, alarm, lighting, etc.)
- Lightning protection management
- Fire risk management
- Explanatory note on labelling and cable marking
- List of spare parts and components supplied
- Note on the possible evolution of the power plant (increase in power, increase in storage capacity, etc.)

- Measurements recorded during commissioning:

- For lead-acid batteries: Battery voltage/density readings in accordance with the manufacturer's recommendations, and detailed record of the battery formatting phase (open lead-acid batteries)
- No-load measurements
- Measurements under load

- Main dates

- Opening date of the construction site
- Date of end of construction
- Date of battery formatting (if applicable)
- Date of commissioning

05

OPERATIONS AND MAINTENANCE

5.1. General considerations

Operation & Maintenance (O&M) is a critical service that should be present in any PV project. Maintenance activities can be divided to:

- Preventive maintenance, which comprises regular visual and physical inspections, as well as verification activities conducted with specific frequencies. It maximizes system output, prevents expensive failures from occurring, and maximizes the life of the power plant.

- Corrective maintenance, which includes maintenance that repairs or fixes a problem that was identified as part of regular service or preventive maintenance, but that occurs as part of the normal operation prior to an actual failure. Corrective maintenance is designed to repair a known problem before it is allowed to propagate into many or bigger problems. Corrective maintenance activities include:
 - Fault diagnosis (also called troubleshooting), to identify the fault's cause and localization
 - Temporary repair, to restore the required function of a faulty item for a limited time, until a repair is carried out
 - Repair, to restore the required function permanently

- Predictive maintenance, which is a condition-based maintenance carried out by evaluating typical patterns of significant power plant's parameters. Predictive techniques help to anticipate and optimize preventive and corrective maintenance activities.

Typically, there are three ways of implementing the O&M phase:

- 1- The contractor is in charge of the O&M for several years.
- 2- The contractor is in charge of the O&M for a short period of time (e.g. one year) and provides training to a beneficiary project's technical team. After the contractor finishes the short O&M phase, the beneficiary takes over O&M duties.
- 3- The O&M is outsourced to a specialized third party.

The choice will depend on the project context, such as the remoteness of the site, the availability of technical personnel on site, the power plant size, whether there is only one site or a cluster of sites, etc.

5.2. Recommended procedures

5.2.1. Preventive maintenance

Preventive maintenance activities shall be carried out at intervals planned in accordance

with the manufacturers' recommendations and as required by equipment warranties. Table 21 shows an example of typical preventive maintenance activities and their frequency.

Table 21. Example of preventive maintenance schedule

Wind Turbines		
Item	Activity	Frequency
1	General Inspection	After first 30 days
2	General Inspection	After 180 days
3	General Inspection	Biannual (but if the other components require annual inspections, might be annual as well)
4	Visual and audio inspection of any abnormal malfunction, sound, or vibration	Everyday
5	Inspection of the tilt-up mechanism of the tower	General inspections
6	Calibrate controllers and sensors	As per manufacturer
7	Inspect mounting structure for abnormal movement and tighten as necessary using torque meter	Annual
8	Test earthing resistance	Annual
9	Check metallic structure for signs of corrosion, remove rust, and re-paint if necessary	Annual
10	Inspect DC cabling and MC4 connectors for signs of defects. Replace damaged MC4 connectors	Annual
PV Arrays		
Item	Activity	Frequency
1	PV module cleaning according to manufacturer recommendations	Every 6 months
2	PV module visual inspection and infrared inspection	Annual
3	General cleaning and vegetation removal. Determine if any new objects, such as vegetation growth, are causing shading of the array and move them if possible; remove any debris from behind collectors and from gutters	Annual

4	Measure the I-V curve characteristics of each PV strings (V_{oc} , I_{sc} , V_{mp} , I_{mp} , and P_{mp})	Annual
5	Calibrate weather sensors and meters	As per manufacturer
6	Test earthing resistance	Annual
7	Inspect DC cabling and MC4 connectors for signs of defects. Replace damaged MC4 connectors	Annual
8	Inspect the PV combiner boxes (if any) - fuse check and replacement, electrical connection tightness and retorquing, water intrusion, corrosion damage, intrusion by pests	Annual
9	Check all hardware for signs of corrosion and remove rust and re-paint if necessary	Annual
10	Inspect ballasted mounting system (if any) for abnormal movement	Annual
11	Torque inspection of PV structure and PV modules	Annual
12	In roof-mounted generators, inspect the roof penetrations to ensure proper waterproofness	Annual

Inverters

Item	Activity	Frequency
1	Perform a remote performance test on the PV generator, considering the measurements of the PV inverter output power, irradiance, as well as ambient and PV module temperature	Monthly
2	Remotely collect and inspect inverter logs (alarms and faults logs)	Monthly
3	Remotely check inverter's well behavior with safe fallback setting	Monthly
4	Inspect housing and/or shelter for physical damage	Annual
5	Clean dust from heat rejection fins	Annual
6	Turn off and on logging and communications to ensure they are communicating and ensure battery backups are working	Annual
7	Check output AC cable connection tightness	Annual
8	Clean and replace air filters	As needed
9	Install any recent software upgrades	As upgrades become available, maximum 5 years
10	Replace surge protection devices	As per manufacturer

Li-ion batteries and BMS		
Item	Activity	Frequency
1	Conduct all preventive O&M necessary to comply with the warranty of the manufacturer. This might include charging up to a certain SoC level on a monthly basis	As per manufacturer
2	Visual inspection of the batteries to check for defects, cracks, leaks, integrity of the enclosure and support structure	Every 6 months
3	Inspect electrical protections and cables	Every 6 months
4	Visual inspection of the communication cables	Every 6 months
5	Check all terminals for corrosion and proper torque	Every 6 months
6	Inspect air conditioning system. Replace air filters as needed	Every 6 months
7	Inspect fire detection and suppression system	Every 6 months
8	Check the registered minimum voltage of the battery modules	Every 6 months
9	Check the battery SoH and assess its lifetime	Every 6 months
10	Check the battery number of cycles completed on the BMS	Every 6 months
11	Check the electrical resistance of each battery module	Every 6 months
12	Inspection of the communication system - all battery modules need to be communicating with the BMS	Every 6 months
13	Collect data for events and alarms, analyze them, and correct if necessary	Every 6 months
14	Thermographic measurement of the battery for potential hotspot detection	Every 6 months
15	Check with the client if any new loads have been added and report. This will affect the system's autonomy.	Every 6 months
Wiring Systems		
Item	Activity	Frequency
1	Inspect all switchboards: Tightness of the electrical connections, corrosion, intrusion of water or insects, sealing	Annual

2	Check proper position of DC disconnect switches and fuses and replace failed fuses	Annual
3	Check proper position of AC disconnect switches and breakers	Annual
4	Inspect cabling for signs of cracks, defects, pulling out of connections, overheating, short or open circuits, and ground faults	Annual
5	Test the disconnect switches to ensure they are not jammed	Annual
6	Test system grounding	Annual
7	Insulation resistance Riso (resistance in ohms of wires, cables to guard against electric shocks and avoid equipment damage from accidental discharges)	Annual
8	Check the SPDs; replace when needed	Every 6 months
9	Thermographic measurements on the electrical connections	Every 6 months
10	Check grounding hardware	Annual

Monitoring System, and Data logging

Item	Activity	Frequency
1	Test monitoring system hardware and its communication	Annual
2	Ensure all documentation is in place	Every 6 months
3	Document the preventive maintenance that has been carried out: Observations, work performed, replacements, meter readings, and system testing results. Include non-conformance reports to identify potential short-term and long term power production issues	Every 6 months
4	Update as-built drawings if necessary	As needed

Diesel generator

Item	Activity	Frequency
1	Inspect the lubricating system (oil leakage, level of engine oil) and correct or provide any replacements	Every 6 months
2	Inspect the cooling system (oil leakage, radiator block, cooling fluid, antifreeze, belt status), and correct or provide any replacements	Every 6 months
3	Inspect the air inflow system (oil gas, resistance of air cleaner, pipe fittings, and joints) and correct or provide any replacements	Every 6 months
4	Inspect the fuel system (leakage, quantity of fuel, pump nozzle, fuel pipe and joints, oil pump) and correct or provide any replacements	Every 6 months
5	Inspect the exhaust system (air leakages, resistance of exhaust) and correct or provide any replacements	Every 6 months

5.2.2. Corrective maintenance

When considering corrective maintenance, the key parameters are diagnosis, speed of response, and repair time.

The O&M contract shall include minimum response times for each type of fault. Table 22, shows an example of the specifications:

Table 22 Example of minimum response times

Fault	Minimum response time
The entire facility is not generating energy (100% generation loss)	Twenty-four (24) hours
Thirty percent (30%) or more energy generation loss	Twenty-four (24) hours
Less than thirty percent (30%) energy generation loss	Thirty-six (36) hours

Common corrective maintenance activities typically include:

- Addressing inverter faults.
- Tightening cable connections that have loosened.
- Replacing blown fuses.
- Repairing lightning damage and surge protection devices.
- Repairing equipment damaged by intruders.
- Rectifying monitoring system faults.
- Repairing mounting structure faults.

Repairs may be delayed only if there is an opportunity to do the repair more efficiently in

the near future and subject to the availability of spare parts.

It is important that replacements are done with components that have identical specifications or with the approval of the project beneficiary, and always in accordance with the manufacturer’s warranty.

5.2.3. Spare part management

In order to facilitate a rapid response, it is important that spare parts are readily available.

A minimum spare part list shall be clearly stated in the O&M contract. Table 23 shows an example of minimum spare parts specification:

Table 23. Example of minimum spare part quantities

Item	As a percentage of total
Wind turbine	2%
Wind charge controller	2%
PV modules	5%
PV charge controller	2%
PV inverter	1%
Battery inverter	1%
Fuses	5%
SPD (DC & AC)	1%

06

FINANCIAL APPRAISAL

Under the SE4S case study, three weather stations have been installed in three separate facilities encompassing the complete coverage of the LBR2. The weather stations were installed for six months during which data was collected to identify the wind potential for each of the three separate facilities.

Reading from facility E1 (Mrah El Chaeb) showed wind speed between 0.1 and 14 m/s with peaks reaching 17 m/s (July to March readings). Metered consumption of the facility showed a demand varying between 444 kWh and 618 kWh (per month) with an average of 562 kWh. The yearly total is estimated to be approximately 6,742 kWh. Meeting this demand with only wind turbines would require the installation of up to two turbines of 6 kW each at 9 m height.

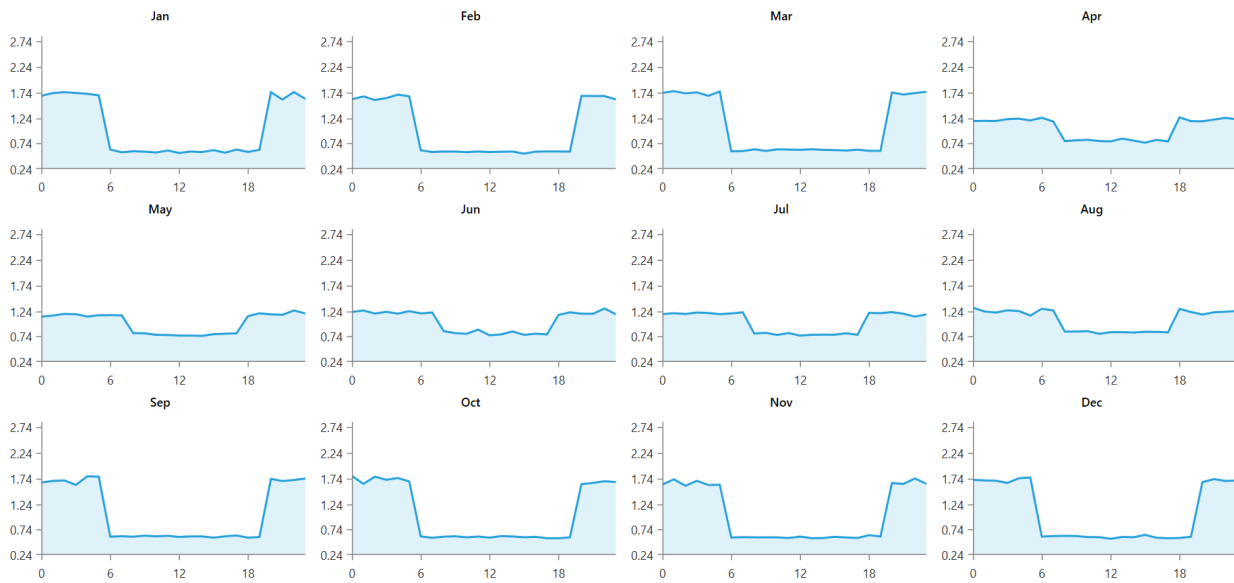
Reading from facility C2 (Al Mdakar) showed wind speed between 0.4 and 15m/s with peaks reaching 17 m/s (July to March readings). Metered consumption of the facility showed a demand varying between 618 kWh and 803 kWh (per month) with an average of 613 kWh.

The yearly total is estimated to be approximately 7,350 kWh. Meeting this demand with only wind turbines would require the installation of up to two turbines of 6 kW each at 9 m height.

Reading from facility A3 (Wadi el Kheil) showed wind speed between 0.4 and 5 m/s with peaks reaching 20 m/s (July to March readings). Metered consumption of the facility showed a demand varying between 74 kWh and 120 kWh (per month) with an average of 95 kWh. The yearly total is estimated at approximately 1,145 kWh. Meeting this demand with only wind turbines would require the installation of one 1.3 kW turbine at 18 m height.

This section provides a financial appraisal of an example hybrid power plant consisting of a 3kW SWT, a 6 kWp PV generator, 30 kWh Li-ion battery, 6 kW battery inverter and the existing 15 kW diesel generator. The example power plant corresponds to one of the actual sites implemented under the SE4S project. The site has a load demand of 25 kWh/day, although the load curve slightly differs from the winter months to the summer months as shown in Figure 7 below.

Figure 7. Load profiles of the site under analysis



The financial appraisal is done by analyzing the Net Present Cost (NPC), Cost of Electricity (COE), Return on Investment (ROI), and payback period of the hybrid system with respect to a power plant that only features the diesel generator. The HOMER software is used for the simulations.

6.1. Cost estimation for the wind generation

Small Wind Technology costs are not commonly described in an open and clear way, and when they do exist, they usually show a very scattered distribution of values, according to size, application, quality, region, and manufacturer. The most detailed analysis on the cost of SWT has been done in the US market, during the 20 years of deployment of this technology. The economic assessment herein will be based on this research. The deployment of SWT in the US has evolved to the wider concept of Distributed Wind. Distributed Wind concept includes both off-grid and grid-connected wind energy systems.

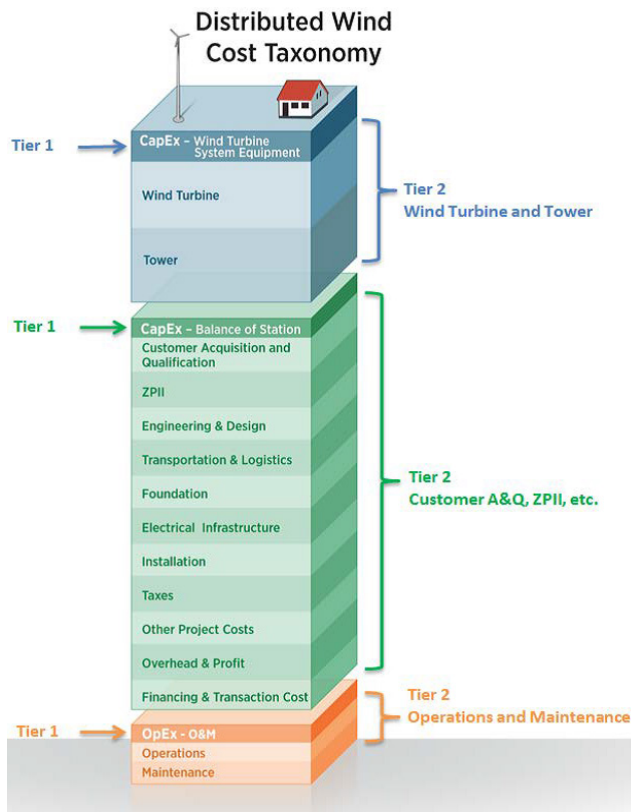
These are the points that will be taken into account to estimate the financial requirements:

- SWT costs classification: organizing costs so they can be aggregated from installers, developers, vendors, and other sources without losing cost details. The classification for a distributed wind installation is shown in Figure 8. The three top-tier groupings are:
 - Wind turbine and tower costs, also known as wind turbine system equipment.
 - Balance-of-system costs, the labor and equipment costs for preparation and the on-site work to install a distributed wind system in a specific location.
 - Operations and maintenance costs, the costs to operate and maintain the distributed wind system throughout its lifetime.

These groupings are followed by second-tier categories, such as rotor assembly, nacelle assembly, and electrical system, and by third-tier or lower-level categories not shown here. The graphic uses abbreviations for two categories: Customer Acquisition and Qualification (Customer A&Q) and “Zoning, Permitting, Interconnection and Incentives” (ZPII) (see Figure 8).

⁴ Forsyth T, Jimenez T, Preus R., Tegen S., Baring-Gould I. “The Distributed Wind Cost Taxonomy”, NREL/TP-5000-67992, 2017

Figure 8: Distributed Wind Cost Taxonomy with the first and second tiers labelled



• SWT costs model: In order to develop reasonable cost extrapolations for those areas in which we do not have sufficient data, the model may have different levels of detail, but at least will include:

- Installation costs: The result of the model for the installation costs, for the US market case, is shown in Table 24:

Table 24: Reference SWT costs

Turbine Size (kW)	Turbin Rated Power (kW)	Adjusted Cost (\$/kW)	Installed Cost (\$)	Min/Max Hub Height (m)
2.4 - 2.5	2.5	10,045	25,113	20/40
5	5	7,785	38,925	30/40
10	10	6,914	69,145	30/40
20	20	6,459	128,186	30/50
50	50	5,858	292,879	30/50
100	100	5,402	540,238	40/50

⁵ Sigrin B., Gleason M., Preus R., Baring-Gould I., and Margolis R. "The Distributed Generation Market Demand Model (dGen): Documentation". NREL/TP-6A20-65231, 2016

- O&M costs: Data on the cost of both scheduled (preventative) maintenance and unscheduled (repair) maintenance were gathered from a wide variety of sources, including manufacturers, leasing companies, installers, and consultants.

The level of certainty at which the data reflects long-term costs varies. These data may not be representative of the average cost in the later part of a turbine’s design life (see Table 25).

Table 25: Operation and Maintenance Cost Assumptions

Rating (kW)	Total Maintenance Trend Line (\$/kW)	Scheduled Maintenance (\$/kW)	Unscheduled Maintenance (\$/kW)	Total Maintenance (\$/yr)
2.5	38.94	27.64	11.30	97
5	38.92	27.62	11.30	195
10	38.38	27.58	11.30	389
20	38.80	27.50	11.30	776
50	38.56	27.27	11.29	1,928
100	38.15	26.87	11.28	3,815

However, as it was mentioned before, the SWT depends also on the region and, in this sense, costs in US renewable energy market are usually higher than costs in other markets,

such as European markets. For instance, the expected costs in the Spanish Renewable Energy Plan for the period 2011-2020 were the following - see Table 26:

Table 26: Revised expected costs for MicroWind in the Spanish Renewable Energy Plan 2011-2020

Turbine Size ->	< 3 kW	3 – 10 kW	10 – 100 kW
Installation costs (€/kW)	> 5,000	3,500 - 5,000	2,500 - 3,500

The referenced data are just a reference and will need to be adjusted to the particular application (Basically, these figures correspond to grid-connected SWT.) and region.

The last issue that will be highlighted here is the cost of the SWT. On one hand, there is a great variety in the cost of similar size commercial SWT: Cost should not be the only criterion to

choose an SWT because, as mentioned before, not all of them will be of the same quality. On the other hand, the information on the cost of a particular SWT is not always easily accessible. The best method is to always have a unique (The cost may be different according to the site.) quotation from the manufacturer/installer; however, some general references can be found in this report.

6.2. Cost estimation for the other components

This set of economical parameters is calculated in different scenarios with different input costs,

as shown in Table 27. The baseline component prices come from actual projects developed by UNDP in Lebanon, and the baseline diesel parameters correspond to the situation in Lebanon as of Q4 2021.

Table 27. Variable input values used in the simulations.

Input variable	Baseline values
Components	PV generator: \$1,300/kWp Li-ion battery: \$400/kWh Battery inverter: \$500/kWac
Diesel	Diesel cost: \$1/liter (adopting conservative \$c35/kWh) Operational costs: \$0.2/h CAPEX: \$0 (the genset is already present)

The following fixed input values are used in all the simulations:

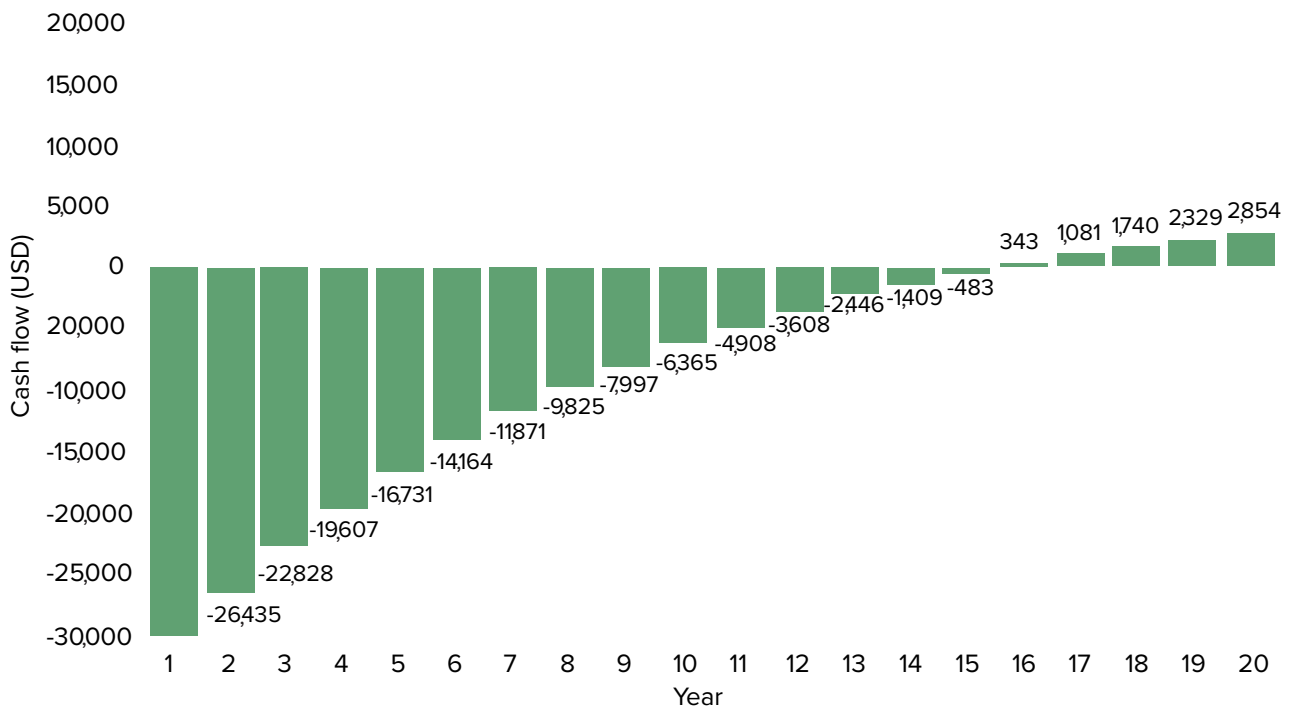
- Project lifetime: 20 years
- Inflation rate: 0%
- Component lifetimes: PV modules 25 years, battery and battery inverter 11 years (replaced once during the project lifetime)
- Battery minimum state of charge: 20%
- Grid sellback price: \$0/kWh
- Real discount rate: 12% (Based on UNDP, 2021. Climate-Proofing Lebanon's Development Plans. Beirut, Lebanon)

6.3. Case study for hybrid micro-wind in Lebanon

To demonstrate the financial performance of the hybrid system, C2 is taken as a case in point. C2 has one available source of electricity: The local diesel network. The proposed solution is adding the hybrid system composed of a 3kW SWT, a 6 kWp PV generator, 30 kWh Li-ion battery, and a 6 kW battery inverter.

Figure 9 illustrates the cash flow of the hybrid system. The Net Present Value (NPV) is 2,854 USD for this case, with a payback period of approximately 15.5 years.

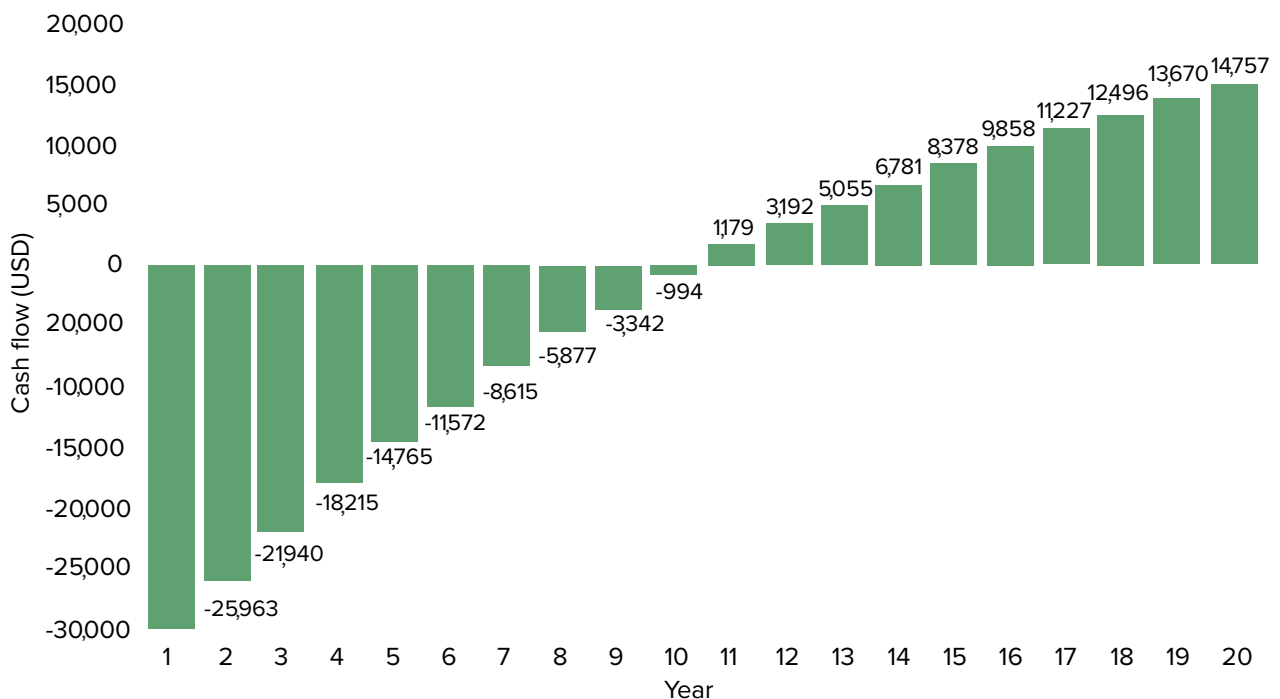
Figure 9: Cash flow for hybrid wind & solar with storage at C2 at 12% discount rate



It is important to note that if the real discount rate is reduced to 8% (a realistic rate if and when the economic and political situation in Lebanon improves), the NPV and the discounted cash

flow analysis would dramatically change, as shown in Figure 10. The NPV changes to 14,750 USD and the payback period becomes approximately 10.5 years.

Figure 10: Cash flow for hybrid wind & solar with storage at C2 (at 8% discount rate)



In the proposed system, the following generation sources serve the electrical load.

The financial performance of the system installed at C2 is cost-effective in relation to the base case, the existing diesel grid. However, it is interesting to compare with the only solar PV-Hybrid solution. The very low cost of solar PV generation makes it difficult for the inclusion of an SWT to compete; in fact, the considered costs of the

solar PV + battery solution has drastically decreased during the period in which the SE4S project has been deployed. However and in the LAF case, the need for reliable power and diversity of power sources to increase energy security on site is the more relevant need. So both criteria were considered: Cost and renewable energy percentage. Figure 11 shows the influence of both criteria.

Figure 11: Renewable Fraction as a function of the System NPC, for systems with (blue dots) and without wind (reddish dots) generation. The green dot represents the selected wind-PV hybrid configuration

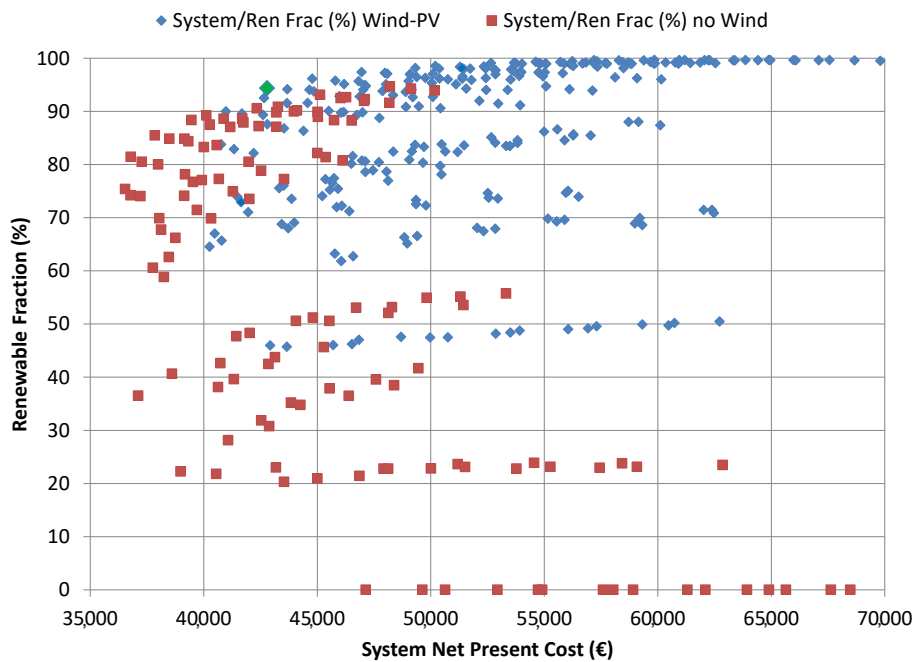


Figure 11 shows how each and every configuration is cheaper than the existing system: Only including storage (reddish dots where the renewable fraction is null) decreases the NPC; adding PV to the storage option usually produces even lower costs (reddish dots, renewable fraction non null); and the systems with wind generation (blue dots) are, in general, less attractive from an economic point of view, than only solar PV with storage (with the considered costs).

However, in this case, the selected wind-PV hybrid configuration (green dot) represents the most competitive configuration to reach a renewable fraction higher than 90%.

Furthermore, the market for micro-wind turbines in Lebanon requires more time and effort to become mature and to reduce the costs of micro-wind turbines and installations.

ANNEX 1: Comments on the Wind Resource Campaign

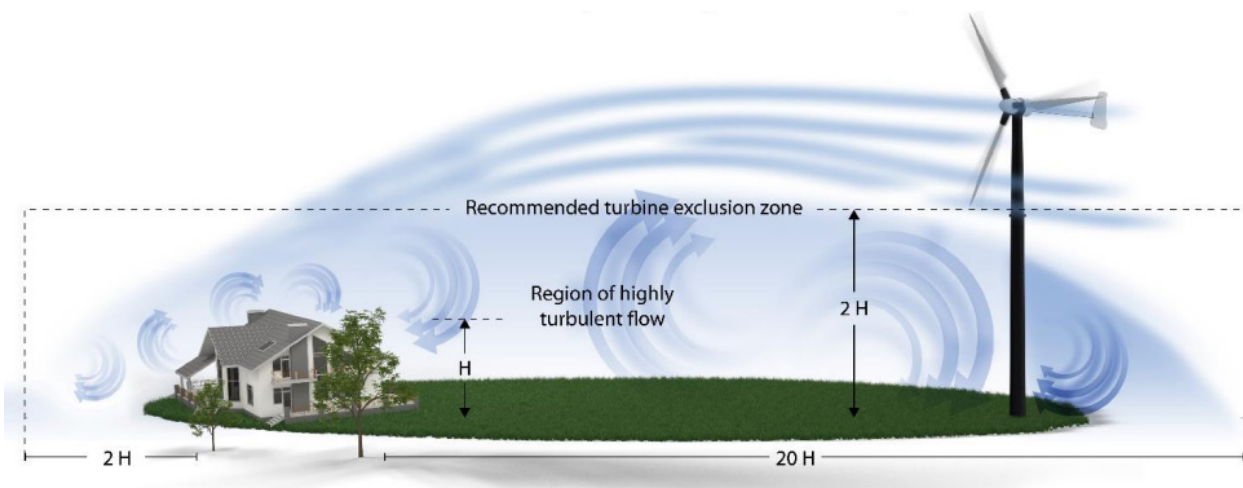
Energy measurements, and even meteorological measurements like temperature, usually have accurate economical measurements; when it comes to the wind resource characterization, this is not guaranteed. The weather station acquired under the “Sustainable Energy for Security Project” is for generalized wind measurement, but it does not at all guarantee that the campaign will have a reasonable accuracy (for example, the one described in the IEC-61400-12 Wind Energy Generation Systems – Part 12-1: Power Performance Measurements of Electricity Producing Wind Turbines). Of course, if the measurement shows high wind potential, this means that the wind potential is really high; but if the campaign ends up with a poor wind potential, this is not conclusive because the measurement itself might be inaccurate.

The wind resource at the sites campaign is expensive. Therefore, if the budget is an issue,

and the only affordable option is the weather station, a recommendation would be to place the wind and vane sensors as high as possible, and as far from the buildings as possible, in order to avoid the turbulence produced by them. If this is not possible either, then it has to be taken into account:

“Turbulence is a stochastic, random, three-dimensional phenomenon that is shown graphically in a simple two-dimensional view (see Figure 12). This graphic depicts an ideal installation of a turbine tower at least two times higher than the highest obstacle and 20 times the highest obstacle horizontally in the dominant wind direction. If the small wind turbine rotor is installed inside the “recommended turbine exclusion zone,” production and reliability may decrease; the project developer should consult with a professional site assessor to understand the resultant impact. This approach is the simplest method to assess obstacles in rural or peri-urban sites and gives the basis for initial consideration of small wind turbines.”⁶

Figure 12. Zone of disturbed flow over a small building



⁶ “Micro-Siting Small Wind Turbines for Highly Turbulent Sites”, IEA Wind TCP, 2018

As a point of reference, in the professional campaign, the net electric power of the wind turbine is measured using a power measurement device (e.g. power transducer) and is based on measurements of current and voltage on each phase. The class of the current transformers shall meet the requirements of IEC 61869-2 and the class of the voltage transformers, if used, shall meet the requirements of IEC 61869-3.

They will class 0.5 or better. The accuracy of the power measurement device, if it is a power transducer, needs to meet the requirements of IEC 60688 and should be class 0.5 or better. For power performance measurements, there needs to be an anemometer with a class better than 1.7A (as described in the aforementioned IEC-61400-12).

ANNEX2: Assessment on micro-wind noise levels and communication interferences

Research and investigations on the “recommended” and “acceptable” wind noise in security / border facilities will be conducted to ensure no disruption is caused by the installed systems to the surveying and security procedures maintained at the border facilities. There are some concerns for noise level; the targeted facilities are border “high risk” facilities and the LAF team depend on their hearing during their night patrols.

Comments on the tower

Some general comments on the tower of the SWT will initially be given since they affect both aspects that will be analyzed. These comments are intended to provide a reference for the height of the SWT (its tower), depending on the size of the SWT (its nominal power).

Depending on the power of the wind turbines, the height of the tower varies. This has a threefold influence:

First, the overall cost of the SWT increases; second, the magnitudes of the wind speeds that are reached also vary; and third, the distance to users and equipment is different. The first two influences will affect the sizing of the system, whereas the third influence will affect both the users’ perception of the noise emitted by the SWT, and the possibility of producing interferences with telecommunication equipment.

The result of a study on the US SWT market ⁷ is presented in Table 28. It shows the sizes of the towers that different commercial wind turbines offer.

Table 28: Tower height (in meters) as a function of the SWT power

SWT Power (kW)	Minimum	Typical	Maximum
2.5	9	14	18
5	24	24	37
10	30	37	43
20	24	30	37
50	37	43	43
100	30	37	37

According to these results, the expected height of the SWT will range within 15-45 meters. The tower height will affect the distance to users and to equipment when considering noise emissions (This is usually already taken into account in SWT certification tests.) and equipment interferences. This is another valid reason (The main one is the influence of obstacles on the wind turbine performance,

described in Annex 1) to distance the location for the wind turbine from the buildings as much as possible, within common sense.

Interference on communications

The possible interference of wind turbines on communications is a recurrent issue in the wind community. As a probe, four IEA Wind Topical Expert Meetings on the Topic “Radar,

⁷ B. Sigrin, M. Gleason, R. Preus, I. Baring-Gould, y R. Margolis, «Distributed Generation Market Demand Model (dGen): Documentation», NREL/TP--6A20-65231, 1239054, feb. 2016

Radio Links, and Wind Turbines” have been organized in the last couple of decades:

- TEM#83 in October 2015. (Wachtberg, Germany).
- TEM#60 in November 2009. (SenterNovem, Netherlands).
- TEM#53 in March 2007 (Oxford, UK)
- TEM#45 on March 2005 (London, UK)

The recurrence comes from the fact that wind turbines are getting bigger and bigger, and wind farms are becoming common in many areas in the world.

For SWT, compatibility with military installations has been studied in the project “Small Wind Turbine Installation Compatibility Demonstration Methodology, ” with the objective of assessing the compatibility of small wind turbines (≤ 100 kW) with army installations, which would help armies both nationally and internationally, by indicating how easily small wind turbines can be integrated into army Installation operations, in places where large turbines cannot be utilized due to safety of flight, and unknown radar anomaly concerns. The plan was to measure radar, acoustic and seismic, turbulence, bird and bat, cold and icing effects, to address the installation of small wind turbines in army facilities, which would guide installation energy managers in understanding the permissions, installation, and performance in a semi-complex environment. Unfortunately, because of budget cuts, not all the experiments were completed.

On the other hand, the use of Small Wind Turbines (SWTs) to supply power to families, factories, and also telecommunications equipment has been progressing. In particular,

the use of the hybrid model of fuel-/wind-/solar powered BTS (Base Transceiver Station) has been adopted in many places around the world.

The typical SWT power outputs considered for BTS are in the range of 1.5 kW to 7.5 kW. This is more significant in the context of LTE 4G network deployment, when compliant BTSs require much more energy than the previous ones. Although these SWT dimensions are obviously small in comparison with those of the big ones, the possible SWT impact on BTSs may occur. Indeed, when SWTs are located on top of BTS mast or on another mast but just behind it, the distance between SWTs and BTS antennas is much closer than that of radars and big WTs. This proximity raises questions about near field and far field electromagnetic (EM) coupling between an SWT and a BTS, and about possible cellular radio communication disturbances. This influence was studied in the OPERA-Net2 Project⁹, but the available results are not conclusive.

Finally, the “Planning Guidance: Small Wind¹⁰” in the UK gave some hints on how to treat these effects:

- Aviation: The majority of small wind systems may not affect radar/aviation assets because of their small scale. The potential impact on radar and radio navigation aids should be consulted if the location and scale of the system justify this. Depending on the range from the airfield, it is quite possible that the system will not present any physical obstruction to aircraft.
- Electronic Communications: It is unlikely that small wind systems affect electronic communications networks and services, but there is a residual risk of three potential effects.

⁸ Charles Ryerson, Kelley MacDonald, Donald Albert, George Koenig, Gary Koh, and Arnold Song, “Small Wind Turbine Installation Compatibility Demonstration Methodology”, US Army Corp of Engineers, 2013

⁹ Tran Vu La, François Le Pennec, Christophe Vaucher, “Small Wind Turbine Generic Model Design for BTS Radio Interaction Studies”, IEEE 24th International Symposium on Personal, Indoor and Mobile Radio Communications: Fundamentals and PHY Track. 2013

¹⁰ “Planning Guidance: Small Wind; A good practice guide”. Renewable UK. 2011

- Interference with Television Reception. The Office of Communications, commonly known as Ofcom, (is the government-approved regulatory and competition authority for broadcasting, telecommunications, and postal industries of the United Kingdom) states that even with large wind turbines “the tower or nacelle rarely has any effect on TV reception” and that the active part of the turbine is the blade system. In contrast, small wind turbine blades are usually constructed from inactive materials such as glass reinforced plastics. If the installed system is under 15m hub height or has non-metallic blades, no consultation is required. If there is metallic content in the blades and the system installation is above 15m hub height, then an assessment is required for all classes of turbine in accordance with the process defined in a document entitled “Tall Structures and their Impact on Broadcast and Other Wireless Services¹¹”.

- Interference of electronic communications through physical blocking: The function of electronic communications installations is likely to be adversely affected by tall structures located nearby since they can physically block radio signals. So for example, panel or omni directional antennas used by a mobile operator can be sensitive to any potential effect on dish links. Small Wind Turbines siting should, therefore, avoid locations in close proximity to electronic communications installations.

- Interference with fixed links: The operation of the terrestrial television network is dependent upon Rebroadcast Links, i.e. radio dish links that typically connect main television transmitters with outlying relay stations. If a dish link is broken by an intervening tall structure, like a wind turbine, then this could have a serious effect on the local operation of the television

broadcast network. It is important to note that radio dishes are often located well below the top of a tower.

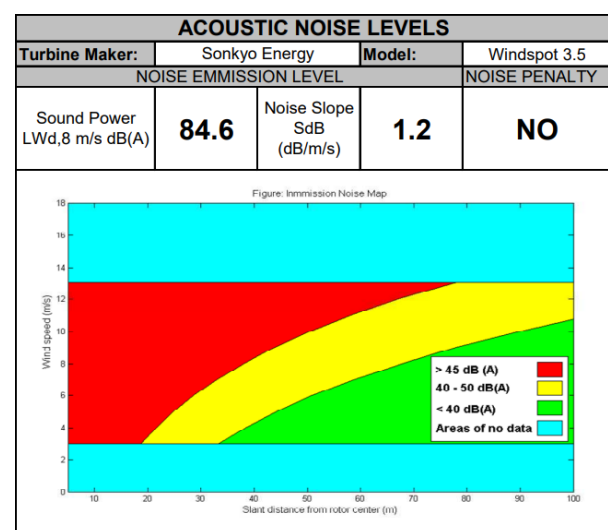
In relation to conducted EMC, the converter through which the SWT connects to the system usually fulfills the international standards for EMC.

Noise emissions

In the “Planning Guidance: Small Wind¹²” in the UK, it is stated that “A threshold of acceptance is suggested if any property would be exposed to noise emission levels less than 45dB (as measured) 1m from any window of an occupied room for 90% of the time.”

The noise emission from any certified turbine is systematically measured in accordance with the reference of IEC 61400-11: 2003, and is presented in the form of a noise map. In the noise map obtained below during the certification process¹³ (and measured by CIEMAT) of the WINDSPOT wind turbine (3.5kW), from the Spanish manufacturer SONKYO, is shown (see Figure 13):

Figure 13: Noise emission map for the Windspot



¹¹ published by OFCOM dated 26 August 2009

¹² “Planning Guidance: Small Wind; A good practice guide”. Renewable UK. 2011

¹³ “Wind Turbine Generator System Summary Test Report for the Sonkyo Energy Windspot 3.5”. Intertek. 2013

It is important to note that this is a specific example and does not mean that all SWT have the same noise map.

This graphic shows the declared noise emission levels as well as calculated noise emission (that is received by the listener) at different distances from the turbine and at different wind speeds. The Sound Power box states that for this particular turbine the noise emitted (that is transmitted from the turbine) has a sound power of 84.6 dB at a wind speed of 8m/s. In this example, in order for a neighboring window to receive a sound pressure level (Lp) above the suggested threshold, it would need to be within 38 m of the turbine hub.

Conclusion to the investigation

In conclusion, the topic of noise (both acoustic and electromagnetic) interference on such an application as the one addressed in this project, is neither easy to handle, nor quick to short out.

In common SWT applications, setting aside any confusion, its use will not bring any interference. The difference precisely comes from the application:

- **Acoustic noise:** The effect that is usually studied is the health effect on users. In this regard, this effect is negligible if the wind turbine hub is located at an appropriate distance (> 50 m). But in this application, the effect to be studied is mainly for security reasons, basically at night, so that the turbines do not prevent the military from hearing what is happening around them. For this purpose, the presented analysis again suggests that placing wind turbines at a certain distance will not have a significant impact. And it will have an even less of an impact compared with the noise coming from the existing genset.

Interference with communications: The general feeling on this possibility is also that the SWT would normally not be a problem. Because of the applications, sensitive electronic equipment might be affected, as well as communications. Experience shows that SWT have been widely used in telecom stations worldwide, without any known experience of interference. However, it would be helpful to choose a wind turbine without metal moving parts (blades) and, if possible, place it at a certain distance (several meters at least) from antennas and from electronic equipment.

ANNEX 3: Sizing based on simple calculations

In the case of sizing Hybrid Wind-Solar PV Systems, annual average calculations are not enough because it is essential to take a temporal relationship between generation and demand. In the case of this simple sizing method, monthly calculations are recommended for simplicity. However, it is strongly recommended to double-check the sizing with specialized software such as HOMER or equivalent.

When considering wind generation in a hybrid system, the easiest way to size the system is to calculate the wind production for each month of the year for a particular wind turbine and subtract it from the corresponding monthly consumption. The result will be taken as the energy demand used for the sizing of other components, which can be performed following the equations set in Section 4 of the Guideline Report “Solar Photovoltaic Hybrid Plants” from UNDP’s CEDRO project.

Small Wind Turbine (SWT) calculations

The annual or monthly wind production may be calculated using the power curve of the SWT and the wind speed probability of the site. Weibull function is the most commonly used for the wind speed probability model. The calculation of the average daily wind production (WP) can be done with the following equation:

$$WP(\text{kWh/day}) = 24 * (1 - SA * 0.0000918) * \sum_{vi=1}^{25} 5P(v_i) * WF(v_i)$$

where:

- SA is the site altitude at the site, in meters (accounts for the air density correction).
- P(v_i) is the power produced by the selected SWT for a wind speed “v_i”, in the power curve.
- WF(v_i) is the value of the Weibull Function for a wind speed “v_i”, which can be calculated as:

$$WF(v) = k/c * (v/c)^{k-1} * e^{-[(v/c)^k]}$$

where:

- v is the wind speed in m/s.
- k is the form parameter, unitless.
- c is the scale parameter, m/s.
- P(v) probability of occurrence of wind speed, v.

For a hybrid system, this calculation should be made on a monthly basis, resulting in twelve average daily productions, one for each month. This model uses k and c parameters for the Weibull function, but it is possible to use parameter k and the average wind speed, which is usually easier to find (Sources of data can be found in section 2.3, which presents a description of the wind resource assessment for SWT.). In this case, parameter c should be changed by 0.89 times the value of the average wind speed for that month. If parameter k is not known, a value of 2 may be used for inland sites.

Monthly average wind speed data should be given at the hub height; if this is not the case, a calculation is needed to convert them at this height. One calculation is, for example, using the power law profile, which assumes that the ratio of wind speeds at different heights is given by the following equation:

where:

- U_{hub} = the wind speed at the hub height of the wind turbine [m/s]
- U_{anem} = the wind speed at anemometer height [m/s]
- Z_{hub} = the hub height of the wind turbine [m]
- Z_{anem} = the anemometer height [m]
- a = the power law exponent

If the wind speed data are gathered from a Wind Atlas at a certain height, that height would be Z_{anem} for this calculation.

The other components

Once the monthly wind production has been estimated, the other main components can be derived using the following equations:

The nominal PV capacity, C_{PV} , can be calculated for each month as

$$C_{PV} (kW_p) = SF \cdot (D - WP) / (PR \cdot PSH)$$

where:

- SF is the Solar Fraction, the ratio of the energy demand covered by the PV generator and the battery over the total energy demand, unitless.
- D is the average daily energy demand, in kWh/day.
- WP is the average wind generation for each month (as described before), in kWh/day.
- PR is the Performance Ratio, the ratio of the produced solar energy over the available solar energy, and this ratio depends on the overall hybrid plant efficiency (unitless). In hybrid plants it is estimated at around 40% - 65% depending on whether the PV generator is oversized or not. The PR will be low if the PV generator is oversized and its production is often curtailed. As a point of reference, in grid-connected plants that dispatch all the PV production, the PR is in the range of 70% - 85%.
- PSH is the Peak Sun Hours, the average daily solar radiation at the selected site, in hours/day. Monthly PSH values shall be used. The PSH at the specific site can be obtained from renowned weather databases such as Solar Resource Maps from the ESMAP/SolarGIS.

The nominal capacity of the battery, C_{bat} , can be calculated as:

$$C_{bat} (kWh) = A \cdot D / DoD \cdot \eta_{bat}$$

where:

- A is the desired battery autonomy, in days.
- DoD is the Depth of Discharge, unitless.
- η_{bat} is the aggregated efficiency of the battery and the battery inverter.

The PV inverter nominal capacity, C_{PVINV} , can be calculated as:

$$C_{PVINV} (kW) = C_{PV} (kW_p) \cdot R$$

where:

R is the power ratio, a value usually between 0.7 and 1 in Mediterranean countries.

The battery inverter sizing ensures that the battery inverter can power the peak apparent power demand. If several single-phase inverters are used to create a three-phase ensemble, the load unbalances should be considered to ensure not to overload any phase. The overload capacity of the battery inverter should consider the surge power requirements of the site, such as those created by motors and compressors.

An MS Excel file with this simple calculation sizing method is available.



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