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Wind Project HV Grid Connection and Grid Code Compliance

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Abstract- HV connection to the high voltage grid for wind projects must comply with the local grid code, which is a set of technical and operational requirements that govern the connection and operation of renewable energy generators to the grid. The grid code is regulated by the local regulatory that are responsible for the transmission and distribution of electricity. Compliance with the grid code is essential for the safe and reliable operation of the wind project. The scope of access to the high voltage grid is a critical factor in the development of wind projects, as it allows for the electricity generated by the wind turbines to be transmitted and distributed to consumers. Direct connection typically requires the construction of a substation and the cost of a direct connection would also include the cost of the incoming and outgoing circuits. In contrast, a LILO (Loop-In Loop-Out) connection would typically require the construction of two substations and the installation of needed equipment at each substation and the construction of transmission lines to connect the two substations. LILO connection can be more expensive than a direct HV connection but offers increased reliability, compliance to the grid code, improved system stability, and increased system capacity.

Keywords- Wind project, Grid Code, HV connection, Loop-in Loop-out, 225kv & 400kv, CAPEX, HV Substations, Electrical transmission, Load analysis

1 Introduction

The full and complete development of a mega wind project takes the longest period in comparison with technical studies, mainly the construction and commissioning. Permitting process and the high voltage grid access are considered as a critical and important milestone in the feasibility study. In most developing countries renewable energy assets need to fit with the operational and technical standards of the grid manager especially for the HV levels. A number of technical standards are applied to govern and control the requirements for the connection to the grid.

The access to the grid remains a full responsibility of the grid manager in reference to the applied standards and in respect of the technical and operational limitations. These standards serve for several purposes to ensure that the generator will be able to operate safely on the grid line, and will not generate any issues with HV line protection or the power quality parameters, and to protect the generator from any faults that have impacts on the distribution power system [1]. The grid code requirements for connecting wind plants to HV power grid will be investigated. These requirements are based on previous technical conditions that have been applied for all the previous and independent power producers.

The scope of this work is to identify suitable solutions and scenarios of connecting the commissioned wind assets to the Moroccan high voltage grid, under the conditions detailed in the grid code of Morocco, on the basis of the technical characteristics of the project, its geographical location, the structure of the neighbouring EHV network available capacity [2].

Referring to the project type, capacity, localisation and the final point of injection, the Direct access and loop-in loop-out (LILO) are the two

methods commonly used for this purpose in Morocco. it is important to comply with local grid codes and regulations when connecting to the high voltage (HV) grid to ensure safety and reliability. Failure to comply with these regulations can result penalties and potential damage to the grid and equipment [3].

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2 OVERVIEW OF GRID CONNECTION REQUIREMENTS

2.1 Asset technical description:

Renewable energy electricity production especially wind project installations can theoretically be freely operated if their maximum total power per site or group of sites owned by the same operator has a controlled power generation system. The local grid code regulates the access referring to some technical constraints and operational process to protect the national grid.

The strategy of the project management team in charge of the project development is to optimize the available connection scenarios to connect the asset to the grid [4]. Figure 1 shows the general layout configuration of the internal 33kV cable arrays used for the 23 WTG scheme:

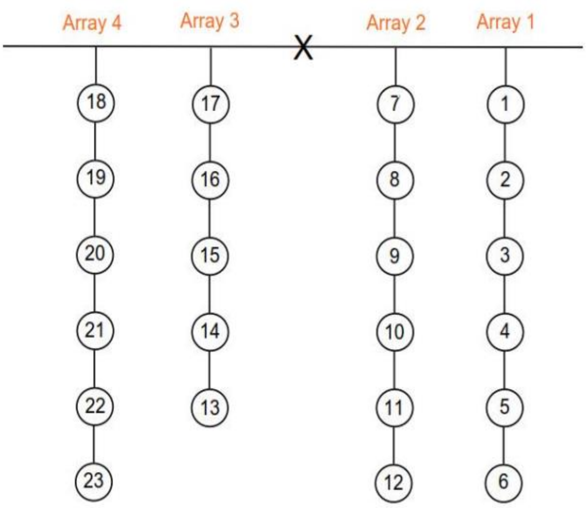

Fig. 1
Internal grid & WTG Layout scheme.

The wind farm is modelled with four 33kV cable arrays using three different cable sizes, the cable sizes were verified through calculations using 33kV cable data from a manufacturer's data sheet. The cable lengths were extracted from the technical file provided by the local grid manager [5].

Wind turbine transformer

- MV Voltage 33kV
- LV Voltage 690V
- Nominal Power 5,350kVA
- Tapping range +- 2 * 2.5%
- Short circuit voltage 9%
- No load loss 3.5kW
- Copper losses 60Kw

Wind Turbine Data

- Nominal Voltage 660V
- Nominal Power 4,500kW
- Nominal Power 5,148kVA
- Sub-transient short circuit current (X") 7.229kA
- R to X" 0.1

Short circuit contribution

The short circuit data and configuration is provided by wind turbine supplier and gives the following short circuit contributions for the LV terminals of the wind turbine.

- Time After Fault 0 – 50ms -> Total Current (RMS) 6.96pu
- Time After Fault 50 – 300ms -> Total Current (RMS) 1.8pu

2.2 Required range of power factor:

Wind plants must participate in controlling the voltage of the transmission network on a continuous, dynamic and fast basis. It needs to be completely equipped with an automatic voltage control system and be able to provide or absorb smoothly the reactive power.

For the mega renewable energy's plants connected to the high voltage and ultra-high voltage ONEE power grid, they have to be able to supply reactive power to the grid to achieve a power factor of between 0.95 lagging and 0.95 leading [6]. The close follow up and monitoring of the process

is essential to make sure of the plant capability of delivering the needed capacity or at least the minimum of the contractual volume.
Following the grid operational model, the reactive power capacity has to be available and supplied in a reliable manner during the following points:

- From: 0 up to 0.3 Pn lagging
- From: 0 up to 0.4 Pn leading

The "Pn" is defined as the total nominal power of the wind plant.

2.3 Frequency deviation:

In the normal operation, the wind power plant connected to the HV-VHV grid side has to operate properly within the range from 50.1 Hz and 49.9 Hz. The small size of the wind farm in comparison to the overall system capacity and the presence of larger generating units, means that any sudden interruption in the wind farm's power output will have minimal effect on the system frequency. This is because the larger units can quickly compensate for the lost power and the system will be able to maintain stability.

Under grid disturbance, a minimum operating period is defined by the frequency range of the electrical system. The frequency deviation is required to meet the requirements as stated in the ONEE's connection requirements:

Table I
Frequency deviation requirements

Frequency range	Trip time (s)
48.5 Hz < f < 52 Hz	Unlimited
47.0 Hz < f < 48.5 Hz	1200 s
46.5 Hz < f < 47.0 Hz	10 s
f < 46.5 Hz	Instantaneous trip

If the system consumption becomes larger than production, the rotational energy stored in large synchronous machines is utilized to keep the grid balanced and as result the rotational speed of these machines decreases. Any decrease in synchronous speed leads to the system frequency to decline until frequency control units of generators increase generation and the frequency is stabilized [7].

According to the National Electricity Grid Code of ONEE, frequency shall be maintained within the following limits:

- Between 49.8 to 50.2 Hz at all times, under Normal State of operation.
- Between 49.5 to 50.5 Hz for a period not exceeding ten (10) minutes under Alert State.
- Between 49.0 to 51.0 Hz for a period not exceeding thirty (30) minutes under emergency State.

As a rough rule of thumb, provided the loss of generation is less than 10% of the capacity on the system, the impact on frequency is expected to be within typical grid code limits. Even under minimum demand conditions, the connected capacity will be more than ten times the size of the wind farm and therefore it can be concluded that the impact on frequency will be minimal [8] [9].

2.4 Voltage deviation:

The wind turbine system connected to the HV-VHV grid side must be able to operate correctly within the following voltage allowed ranges at the point of connection (on the ONEE side) instantons control is applied:

- 60 kV grid: ± 10%
- 225 kV grid: +8,7%/-10%
- 400 kV grid: ± 5%

Under specific grid disturbance, the fault ride through (FRT) requirements which are: the minimum acceptable voltage during the fault (Vmin), fault duration, voltage restoration time and steady state voltage, are represented in the next figure (Un: Nominal Voltage):

Fig. 2
Voltage fault duration

2.5 Threshold values of flickers and harmonics:

2.5.1 Threshold values of flickers

The voltage flickers are the frequent variation of voltage which could lead to modulations of light intensity of incandescent. The threshold values of flickers are given in term of Short-Term Flicker Perceptibility (Pst) and Long-Term Flicker Perceptibility (Plt) (according to the constant flicker measurement required by the standard IEC61000-4-15 to generate statistical values for short term flicker (Pst), over 10 minutes, and long-term flicker (Plt), over 2 hours):

- Pst: 0.8
- Plt: 0.6

The flicker analysis is part of the power quality studies and has the purpose to assess voltage fluctuations at the point of connection. These fluctuations are in general caused by a significant variation of the output power being generated by the wind farm [10] [11].

The flicker consists of a visual sensation caused by intensity fluctuations of lighting. Such fluctuations are originated by a series of rapid variations of the voltage. The level of experienced instantaneous flicker is a quadratic function of the amplitude of the light variation and therefore of the fluctuation of voltage. Beyond a certain threshold the flicker becomes annoying and the discomfort of the observer grows very rapidly with the amplitude of the fluctuations.

The output power of a wind farm could be particularly intermittent during days of wind velocity reduction or wind turbulence, or when at least one of the towers is shadowed or when a generator or power converter experience oscillations at frequencies near 8.8 Hz. The intermittent power output of the WF system causes the voltage at the point of connection to change frequently throughout the day [12]. The voltage fluctuations then create flicker at the point of connection.

2.5.2. Threshold values of harmonics

The recommended threshold values of harmonics voltage are given in the next table :

Table II
Harmonics values

Odd orders no multiple of 3		Odd orders multiple of 3		Even orders	
Harmonic order	Harmonic voltage (% of Un)	Harmonic order	Harmonic voltage (% of Un)	Harmonic order	Harmonic voltage (% of Un)
5	2	3	2	2	1.5
7	2	9	1	4	1
11	1.5	15	0.3	6	0.5
13	1.5	21	0.2	8	0.4
17	1	>21	0.2	10	0.4
19	1			12	0.2
23	0.7			>12	0.2
25	0.7				
>25	0.2+0.5*h/25				
Total Harmonic Distortion (THD): 3% for HV-VHV					

2.5.3. Threshold values of Voltage Unbalance

Voltage unbalance occurs when the line voltage, phase voltage or phase angle separation in a three-phase system are not equal between all phases. The exact definition, as found in IES 61000 2-2, are expressed as the ratios of the negative and zero-sequence components to the positive sequence component.
The threshold value of the voltage unbalance is 1% on the basis of IES 61000 2-2 [13].

3 Grid Connection Assessment :

The scope of this task is to identify suitable solutions of connecting the wind energy plants to the Moroccan grid, under the conditions detailed in the section above on the basis of the technical characteristics of the project, its geographical location, the structure of the neighbouring EHV network.

3.1 Asset configuration:

The total projected installed capacity of the wind project is 103 MW. The selected turbine for the plant is a unit rated power of 4.5 MW (boosted to 4.6 MW for high wind speeds). The site is equipped with 23 Machines (WTG) on 4 grapes.

As shown in the figures below, 4 arrays connected to a substation with two transformers. The park is about 5 km far from the grid operator HV line (225 KV structure):

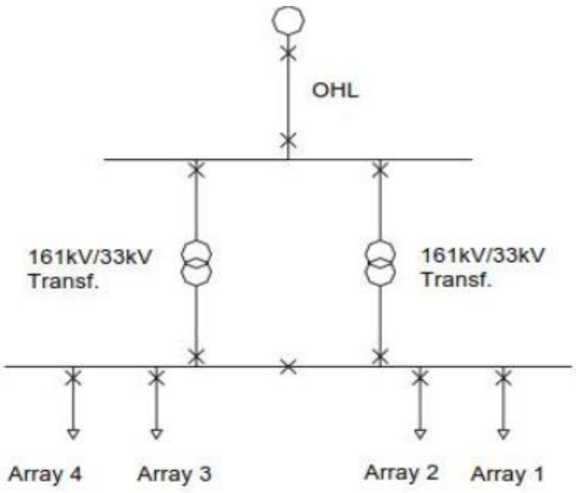

Fig. 3
Internal Grid & Substation

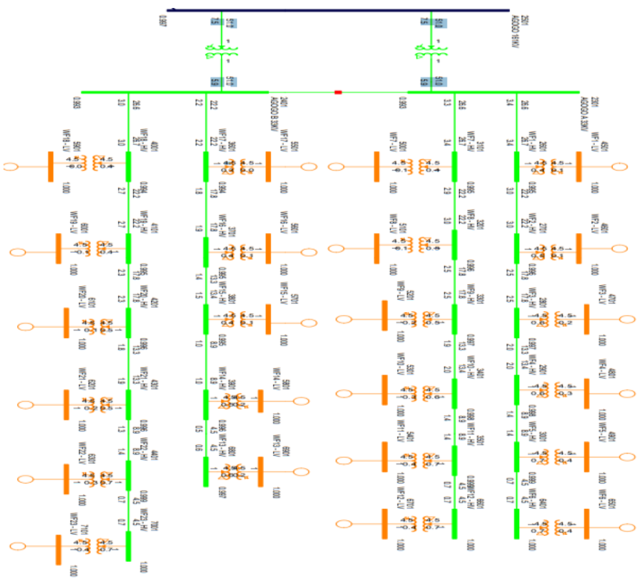

Fig. 4
Full Electrical Grid

3.2 Technical assumptions:

Load flow studies were undertaken to assess the steady state performance (voltage conditions and thermal ratings) of the electric power system. These studies are used to identify patterns of power injection from the proposed wind plant to the rest of the transmission network, and potential congestion points. The technical performance was assessed according to the requirements of the transmission planning criteria [14]. In the analysis of voltage profiles, the local grid operator through the Electricity Grid Code establishes that voltage magnitudes shall be kept within the following limits:

- ±5% of the nominal voltage at all times under normal State.
- ±10% of the nominal voltage under Alert State for a period not exceeding 10 minutes.
- ±10% of the nominal voltage under Emergency State for a period not exceeding 30 minutes.

The following operational cases were theoretically analyzed and evaluated:

- Original Case - National Grid with WF switched off.
- Wind farm Case - National Grid with WF switched on.

Analysis of these two cases and comparison of the results of simulations allows to directly assess the impact of the wind farm plant on the operated power system. The analysis carried out by WSP comprised the 33kV and 225kV networks only. For above cases, two different regimes with regards to the load demand were modelled and simulated:

- Maximum demand (∼98% of peak loading for 2021).
- Minimum demand (∼83% of peak loading for 2021).

Peak load was considered to be similar to the two past years. In all of the analyses for the wind farm case, unless otherwise explicitly stated, the wind project was simulated with maximum active rated power of 103 MW (boost capacity not considered) and 0.95 power factor (lagging) [15] [16].

4 Connection scenarios and RESULTS :

4.1 Grid access scenarios:

Given the projected rated power of the wind farm, the supply voltage level should be at least 225 KV. It emerges from the examination of the state of the site and its geographical position in relation to the VHV lines passing "beside" the park (sketch of situation below), the variants of VHV connections:

- **Scenario 1 (Direct 225kv):**

A direct connection to the 225kV line refers to a direct electrical connection to a high voltage transmission line with a voltage rating of 225kV. This type of connection is typically used to transmit large amounts of electrical power over long distances from power generating sources to distribution systems. It may be used in industrial, commercial, or residential settings [17].
A direct connection to 225kV line typically involves the installation of a substation, which is a facility that is used to step down the voltage of the incoming transmission line to a lower level that can be used by local distribution systems. The substation will typically include equipment such as transformers, switchgear, and protective devices that are used to control and regulate the flow of electricity.

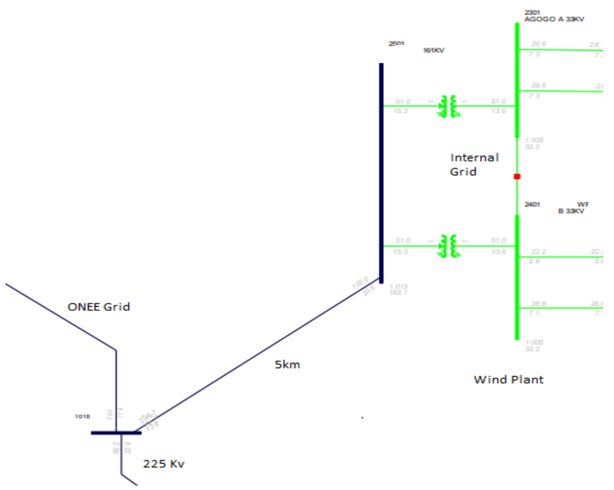

Fig. 5
Direct Connection to 225kv.

In order to make a direct connection to the 225kV line, a facility or site would need to be located within close proximity to the transmission line, and would also need to meet certain technical requirements in terms of electrical load and power demand. The connection would also typically require a detailed engineering study to ensure that the connection is made safely and that the facility or site can handle the power flow.

- **Scenario 2 (400/225kv):**

A 400/225kV line would typically involve the use of a transformer to step down the voltage from 400kV to 225kV at the substation. The substation would also include equipment such as switchgear, and protective devices that are used to control and regulate the flow of electricity.
In order to make a direct connection to the 400/225kV line, a facility or site would need to be located within close proximity to the transmission line, and would also need to meet certain technical requirements in terms of electrical load and power demand. The connection would also typically require a detailed engineering study to ensure that the connection is made safely and that the facility or site can handle the power flow.
As the 400 kV is a high voltage level, the connection point would have to be a substation or a switchyard, where the voltage would be transformed to a medium voltage (22kV or 33kV) level. From there, the electricity would be distributed to the end user [18].

The line is double-circuit, with a 400 KV structure for the most part and in 225 KV at the approach of the wind farm site. The hypothesis of lowering this work on the park will require the realization of this section and the evacuation station VHT / MV of the park in 400 KV, the connection in first stage of transformers VHT / MV in 225 KV / 33KV and their replacement in 400KV / MV once the line will pass in 400 KV.

- **Scenario 3 (LILO 225kv):**

A Loop-in Loop-out (LILO) 225kV connection refers to a type of electrical connection used in high voltage transmission systems (adopted recently in Morocco). This allows for the transmission of electrical power from one line to another, allowing for more flexibility and redundancy in the power grid.
In a LILO connection, two transmission lines are connected together at two substations, typically through the use of circuit breakers and transmission line reactors. This allows for the power to flow in either direction between the two lines, depending on the power demand and supply on the grid [19].

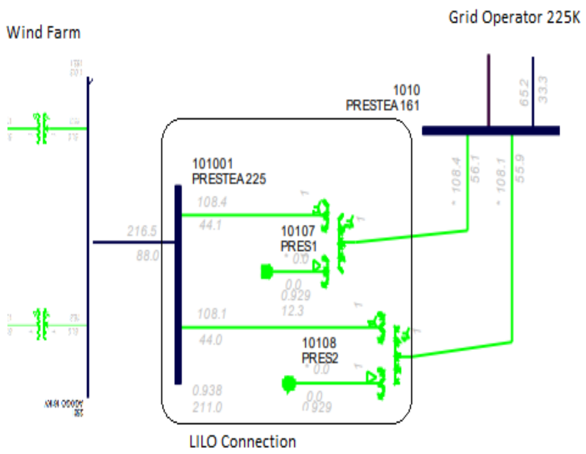

Fig. 6
LILO HV Connection.

A LILO connection has several advantages, such as:
- Increased reliability of power supply: It allows for power to be rerouted in case of an outage on one of the lines, providing a backup supply.

- Improved system stability: The LILO connection allows for better control of power flow and voltage stability, which helps to improve the overall stability of the grid [20].

- Increased system capacity: By allowing power to flow in either direction, LILO connections increase the capacity of the transmission system, allowing for more power to be transmitted over the grid.

4.2 Results:

It is important to configure the most suitable solution in respect to the applied guidelines of the grid code. The configuration of the grid access for wind plant needs to take into consideration the allowed facilities and avoid the local presented constraints.
The Investment cost (CAPEX) for a direct connection and a Loop-in Loop-out (LILO) connection can vary significantly depending on a number of factors, such as location, distance from the transmission line, and the specific equipment and infrastructure required. The Capex and conformity to the grid code parameters are the most consideration to access the HV line [21].
However, it's important to note that the LILO connection or direct HV access to the grid would have to be done by a qualified study referring to the grid code and would have to be approved and validated by the grid operator and the regulatory authorities before being implemented [22]. Direct grid access remains applicable for some specific cases where the plant is located far away from the HV grid corridor.

5 Conclusion

Grid access is an important step in the development of wind projects, it takes a deep engineering and financing feasibility simulations. Connection to the high voltage (HV) grid is a critical factor in the development of the projects, as it allows for the electricity generated by the wind turbines to be transmitted and distributed to consumers. Without a reliable connection to the HV grid, the electricity generated by the wind farm would have to be stored or discarded, reducing the overall efficiency and profitability of the project.
A direct connection typically requires the construction of a substation, including the installation of substation equipment, such as transformers, switchgear, and protective devices, as well as the construction of the substation building and asso-

ciated infrastructure. The cost of a direct connection would also include the cost of the incoming and outgoing circuits, including the transmission towers or poles, conductors, and other components.

In contrast, a LILO connection would typically require the construction of two substations and the installation of substation equipment at each substation, including transformers, switchgear, and protective devices. In addition, the LILO connection would require the construction of transmission lines to connect the two substations. The cost of a LILO connection would also include the cost of the incoming and outgoing circuits, including the transmission towers or poles, conductors, and other components at both substations.

In general, a LILO connection can be more expensive than a direct connection because it requires the construction of two substations and the transmission lines to connect them. However, the LILO connection offers increased reliability, improved system stability, and increased system capacity, which can offset the higher capital costs.

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