

# Evolving Power Quality Standard requirement for a renewable based grid in NEOM

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**Abstract** — Utilities throughout the world are using various industry standards and guidance for setting power quality requirements to manage the significant uptake of renewables in the existing electricity network. From the perspective of an electricity industry aiming to de-carbonize, the power quality requirements will have to cope with the demands of a different portfolio of energy resources to reflect the net zero ambition of most countries. The net zero challenges posed by (1) incorporating significant amount of renewable energy and storage sources (e.g. wind, solar, battery) at transmission and distribution voltage levels interfaced through power electronic interfaces, (2) demand for interconnection across different jurisdictions using HVDCs to accelerate and facilitate the integration of renewables into the network and (3) increasing demands at distribution level which are mainly of power electronic interfaced intermittent loads all collectively impacts on power quality performance and will have to be carefully evaluated. NEOM is a future electricity grid being constructed in Saudi Arabia which will be solely based on renewables and interconnected to the other operating area jurisdictions through HVDC interconnectors with NEOM independently operated by its own system operator (ENOWA). This paper will present the work carried out to evaluate the crucial aspects of power quality (harmonics and rapid voltage change (RVC)) that affects the development of the power quality (PQ) standards to address the requirements of the NEOM 100 percent Renewable Energy Sources (RES) based future electricity grid.

**Keywords** — *power quality standards, harmonics, rapid voltage change, voltage step change, HVDC, wind, solar, battery, transmission, distribution*

## I. INTRODUCTION

Electricity networks throughout the world are all going through a transformation albeit at different paces. At whichever pace, the race is ultimately to achieve reduction in carbon emissions and the common goal is to embrace renewable sources of energy and eventually removing fossil fuel-based generation. This transformation involves significant use of power electronic interfaces to connect the renewable energy sources, storage energy sources, use of HVDC links and involves different layers of complexity to ensure secure operation and coordination of all these different equipment. NEOM, a future electricity grid being constructed in Saudi Arabia is aimed at achieving beyond carbon zero

ambitions and interconnected via HVDC and independently operated by its own system operator (ENOWA).

Due to the incorporation of PE based technologies at all voltage levels in the NEOM network, one of the key areas of concern is power quality. Many aspects of power quality were investigated and studied and, in this paper, two key primary power quality parameters, harmonics and rapid voltage change (RVC) which have been comprehensively studied for the NEOM network is presented.

This paper will (1) discuss the concern and the analysis requirement of the power quality parameters (a) harmonics and (b) rapid voltage change (RVC), (2) present the comprehensive modelling development and studies to justify findings of the results and (3) support recommendations to the development of the power quality standards for NEOM.

## II. METHODOLOGY FOR ASSESSING KEY POWER QUALITY PARAMETERS (HARMONICS AND RVC)

### A. Analysis and Management of harmonics

Harmonics are the presence of unwanted distortion on top of a power signal. An ideal alternating current power source would produce a 50 (or 60) Hz sinusoidal waveform. However, due to certain types of generation, transmission components and loads, this waveform can become distorted with the presence of harmonics on top of both the voltage and current waveforms. This is especially true for converter-based generation, where power electronics are used to artificially create a sinusoid with the resultant signal having distortion due to the effects of the utilised power electronics. Harmonics can cause certain equipment to deteriorate or function improperly. Power quality standards usually impose some form of maximum harmonic levels to limit the effect of distortions on the network. Presence of BESS, subsea cables, VFDs etc. – also at distribution level network connected to NEOM (case example of a Test system in Red Sea shown Figure 1 will impact harmonic levels on Test island system itself and possibly the external NEOM system) and have to be considered.

### B. Analysis and Management of Rapid Voltage Change

Voltage Step Change (VSC) specifically refers to the settled voltage after a rapid voltage change has occurred but before

tap changing action has been performed, i.e. the steady-state voltage change.

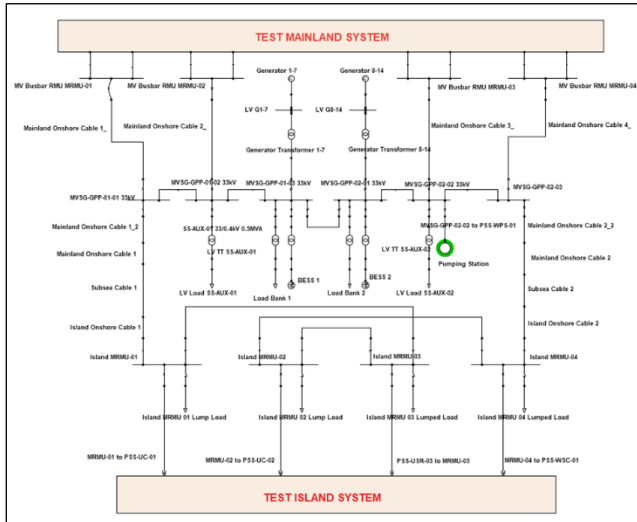


Figure 1. SLD of Test network distribution system connection in NEOM

Rapid voltage change (RVC) refers to the general occurrence of a fast RMS voltage change. These can occur due to loads/generators being connected/disconnected, inrush of transformers and other devices as well as large power swings that can be expected due to the change in the mode of operation of energy storage systems such as Battery Energy Storage Systems (BESS). These voltage changes can have detrimental effects on the network and cause damage or incorrect tripping of generators and loads. Usually, power quality standards limit these RVCs to under certain values for ensuring reliable network operation. This is evident in the case of Test system (Figure 1) which has BESS and non-converter-based generation, and their influence on RVC behaviour is another key parameter to be considered.

### III. JUSTIFICATION AND STUDY FINDINGS FOR KEY POWER QUALITY PARAMETERS (HARMONICS AND RVC)

#### A. Models for studying harmonic impact and results

Due to NEOM's unique topology, as well as full penetration of renewable energy sources which are mainly power electronic interfaced, as well as use of HVDC interconnectors, it was determined that the harmonic distortion levels and procedures within the Power Quality Standard should be rationalized by studies to validate these recommendations.

A ground up approach was taken to incorporating harmonic elements into the provided load flow model. This involved categorically including resonance characteristics in the base Power Factory model based on existing standards and technical recommendations, as well as the emissions of certain network equipment.

Models of overhead lines and cables were adjusted to include resistive damping qualities as well as distributed impedance parameters relevant to the length and voltage.

Transformers were also modelled according to their damping qualities according to the transformer size, voltage and whether it was two or three winding.

Loads were represented with harmonic properties according to their size and voltage, and classified according to whether they were residential, commercial, light industry or

heavy industry to get a realistic mix of loading. These were distributed appropriately according to size and location of existing loads on the provided load flow model.

Manufacturer data was not available for generators and the HVDC sources, so emissions were based on generic data and calculations on the based on the types of converters and connection voltages. All large generators were considered as voltage source converters (VSCs), and HVDC links were considered as MMC type. In general, the worst-case emissions were considered to represent the most potential harmonic distortion for deriving onerous recommendations for the standard. In considering the main elements of harmonic distorting loads in the NEOM system, major connections are discussed below:

#### 1) Wind Farms

The wind farm per cent rated harmonic emissions for the different voltages in association with an area in the NEOM Grid with a wind farm connected at 380 kV is shown in Figure 2.

Harmonic load flow distortion study was carried out for key areas of the network for the harmonic range from the 2<sup>nd</sup> to the 100<sup>th</sup> harmonic order. Results are shown in TABLE I for 380 kV to demonstrate a key finding of planning level exceedances caused by the large generator connections and solved at the PCC using a tuned filter at the transmission level. However, it was also noted that some issues may be more easily solved within the customer wind farm owned network. There is only one exceedance above 0.1% above the 50th order but did not impact further into the utility system. Similar results were obtained for the other voltage levels at 132 kV and 33 kV where exceedances were identified to be caused directly by the large wind farm connections.

#### 2) Traction loads

SFCs were modelled as mixture of 2-level and 3-level neutral point clamped voltage source converters (VSCs) to consider the worst case. These SFCs form the primary load for the traction system and one of the main sources of harmonic distortion.

In addition, the traction system includes a mix of typical resistive and inductive loads that serve as auxiliaries to the primary electromotive loads. ENOWA provided a list of these loads which were included along with the SFC model.

The traction system at each 132 kV BSP (Bulk Supply Point) has multiple RFSs (Rail Feed Stations) and TPSs (Traction Power Substations) that connect to it via different cable lengths between the BSP 132 kV and the TPS sites. Templates containing the detailed traction system is shown in Figure 3 and considers differing cable lengths connected to the BSP. These templates were then included in the model at a 132 kV BSP busbar shows one of the traction connections using this template is shown in Figure 4.

Harmonic load flow distortion study was similarly performed on the impact from traction systems on the NEOM network. This resulted in exceedances above planning levels at the 132 kV BSPs. Appropriate damping filters were required to mitigate these exceedances at the 132 kV BSP.

The harmonic exceedances and waveform for the same 132kV busbar can be seen in Figure 5 with and without filtering. The exceedances can be effectively resolved by suitable design and placement of the filter.

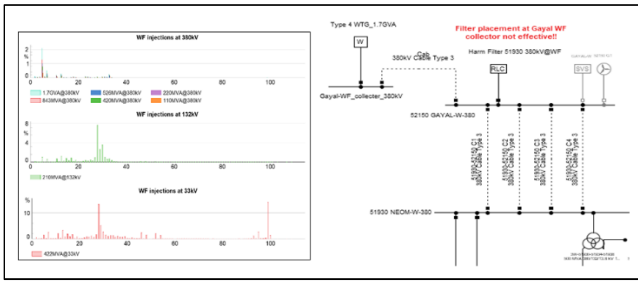


Figure 2 Wind farm connected at NEOM transmission system

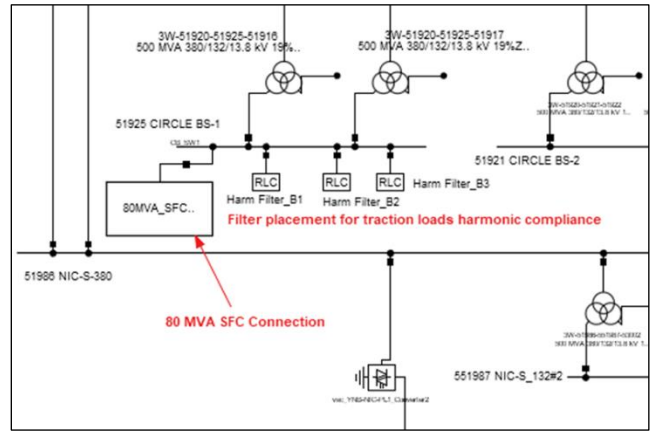


Figure 4 A traction system connected harmonic load using developed template in NEOM system

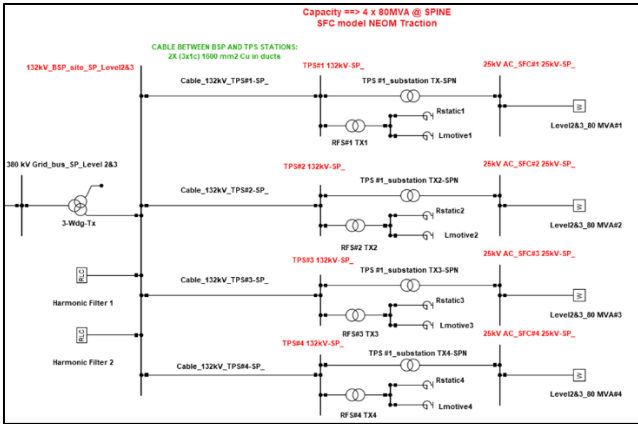


Figure 3 Detailed traction system in NEOM developed for harmonic studies

TABLE I Tabulated results of a large wind farm exceedance at 380 kV

380 kV - Up to 50th Harmonic order					
Busbars	Harmonic orders (non-compliance)	Worst harmonic voltage (% HD)	IEC P.L. exceeded (to 50th)	Assumed Cause	High level filter recommendations from studies
380kV	33	0.27	1	1.7 GW Wind Farm	50 MVar Single Tuned 33rd
380 kV - Up to 51 <sup>st</sup> to 100 <sup>th</sup> Harmonic order					
Busbars	Harmonic orders (non-compliance)	Worst harmonic voltage (% HD)	0.1% as limit consideration	Assumed Cause	Impact
380kV	99	0.16	1	1.7 GW Wind Farm	No effect downstream

**B. Models for studying RVC impact and results**

There is a concern around rapid voltage change in the NEOM network due to the high presence of converter-based generation. However, converters also respond faster to voltage changes than traditional synchronous or “spinning” generation. Because of this, a very slightly less restrictive rapid voltage change limit was chosen for NEOM. To validate this choice, a simple dynamic RMS rapid voltage change study was performed in Power Factory.

This was done using the following methodology:

- Determining ratio of non-converter based generation/storage to converter based generation/storage in the NEOM network. Based on anticipated likely generation profile on the network, three scenarios were considered to be studied: (1) 100% converter generation, (2) 60% converter generation and 40% synchronous/asynchronous generation – based on 17630 MW total generation

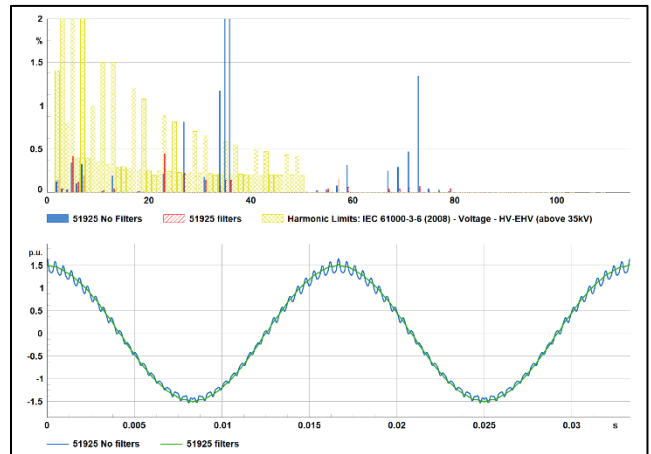


Figure 5 Harmonic exceedances at one traction connection site (showing harmonic levels and waveform for with and without harmonic filter)

with a converter contribution of 10530 MW and (3) 100% synchronous generation (baseline).

- Building of a simple generic 33kV/132 kV network based on fault level information determined from the NEOM load flow model is shown in Figure 6. This is the primary determining factor for Rapid Voltage Change, where a lower fault level means that a higher voltage change can be expected, but also means that generation has more ability to support voltage. The generic model consists of 2 generation sources, using an external grid with a low fault level of 6.959 kA corresponding to an area of NEOM with this fault level, BESS generation sources using the WECC model, with representative planning design data for transformer and cable types used.
- Inclusion of accurate ratios of converter and synchronous generation, represented as lumped IEC, IEEE or WECC dynamic models [1]. The appropriate 9 dispatch of different converter and non-converter were obtained by suitably scaling the generation (conventional and non-conventional by adjusting the number of parallel generator machines, BESS units).
- Comparison of ability of NEOM generation mix to respond to rapid voltage change compared to 100% synchronous generation. If the ability of NEOM network is better in mitigating Rapid Voltage Change than a traditional network, then the slightly less restrictive limits are appropriate. Figure 7 and TABLE



#### D. RVC assessment and compliance process

It can be seen from the results described in Section III that converters can respond much faster to voltage changes than traditional generation. It should also be considered that the generic WECC model used is a few years old at this point, and modern converters allow much more grid voltage support. Because of this expected resilience of a fully modern power system to rapid voltage change, as well as modern end-user equipment such as LED lighting, it is recommended that a simplified two-tier non-restrictive approach is applied for NEOM across all voltage levels:

- For any switching events that occur at least once every 24 hours or more, the maximum voltage change should not exceed more than 6%, reduced to 3% at 1sec.
- For switching events that occur less frequently than once every 24 hours, the maximum voltage change should not exceed 12%, reduced to 10% at 100 mS and 3% at 2 sec.

These chosen requirements are based on modified values of the UK and USA standards.

#### V. CONCLUSION

This paper presented the challenges of a future grid in accommodating a significant amount of renewables in the system. NEOM is a grid with 100 percent RES and sits in a region in Saudi Arabia which is also interconnected to the Saudi National grid (SEC) in Saudi Arabia. Therefore, the proposed power quality requirements for NEOM also has to consider the requirements of the SEC grid at the Point of Interconnection (POI) with SEC grid. Two key power quality parameters, harmonics and RVC have been investigated with comprehensive studies to justify the recommendations being proposed for the NEOM power quality standard. The findings

of this work has highlighted that requirements might have to be relaxed for within NEOM system due to the higher proportion of converter based loads and generation compared to the wider SEC grid. The work carried out and presented in this paper does not just apply to NEOM future grid but is a challenge for utilities throughout the world in grappling with the existing standards and guidance evidenced by ongoing work by industry to reflect the ongoing challenges [5].

#### ACKNOWLEDGMENT

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