Utilization of STATCOM Systems at Wind Power Plants to Meet Reactive Current Injection Requirements During Faults

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***Abstract* - Utilities all over the world have developed comprehensive interconnection rules and grid codes that require wind power plants to have similar operational characteristics to conventional generation. A major component of these requirements is the supply of reactive current during faults. A common starting point in the development of reactive current requirements is to prioritize reactive current without specifying a minimum amount in relation to a change in voltage. The new Indian grid code is an example of this nonspecific reactive current requirement. Other regions, such as the UK, Australia and Jordan, have implemented a more specific requirement where the amount of reactive current injection is defined in relation to changes in voltage. In this paper, the Jordanian grid code is used as an example to demonstrate the use of a STATCOM at a large-scale wind power plants to meet specific reactive current requirements.**

Keywords- Grid Code; STATCOM; Reactive Current; low-voltage ride-through

I. INTRODUCTION

In order to maintain the reliability of a transmission system as the renewable energy penetration increases, many utilities and regulators around the world have expanded their grid codes to require certain performance from inverter-based renewable generation. One of the most important aspects of these grid codes for Wind Power Plants (WPP) is the voltage ride-through requirements. At a minimum, these consist of simple voltage vs. time diagrams with a region where tripping is not allowed as shown in Figure 2. In addition to these simple voltage ride-through diagrams, some grid codes define specific reactive power support requirements. For example, the new Indian grid code [1] requires that a WPP to provide as much reactive power support as possible during low-voltage ride-through (LVRT), but do not prescribe how much this reactive power injection needs to be. In other countries, such as Germany [2], the UK [3], and Australia [4], which already achieved a higher level of renewable energy penetration, more stringent reactive power requirements can be found that define a precise amount of additional reactive current per given voltage change, measured either at the terminals of the equipment or at the Point of Interconnection (POI).

In the most recent Indian Grid Code, published 8 February 2019 [1], the amendment requiring the WPPs to prioritize the supply of reactive power during voltage dips is an example of a grid code evolving from prioritization of real power to reactive power during faults. In the next few years, as the renewable energy penetration increases in India according to the governments' renewable energy targets, the reactive power requirements may further evolve to become more stringent, prescribing a precise amount of additional reactive current, to maintain transmission system reliability.

Another approach in developing grid codes for renewable energy integration is to survey the experiences of other countries and pick the best practices from each. The Jordanian grid code [5] provides a good example with clear, prescriptive requirements for reactive power support during faults. In this paper, a case study of how a Jordanian WPP is made compliant with the reactive power requirements of the grid code is presented.

A summary of the Jordanian grid code is presented in the next section followed by simulation results of an example WPP in Section III, where a reactive current deficiency is observed when only the wind turbine capability is used. In section IV, addition of a STATCOM is presented as a potential solution to address the reactive current deficiency. The paper concludes with the key takeaways given in Section V.

II. JORDAN GRID CODE

The Grid Code put forth by the Jordan National Electric Power Company (NEPCO) [5] contains steady state reactive power, voltage ride-through, and reactive current injection requirements.

A. *Reactive Power Requirements*

The NEPCO reactive power capability requirements are illustrated in Figure 1. The Grid Code specifies that the WPP must be able to achieve a Power Factor (PF) of 0.95 inductive and 0.85 capacitive at full generation as measured at Point of Common Coupling (PCC). This same level of reactive capability must be provided between 10% to 100% generation levels.

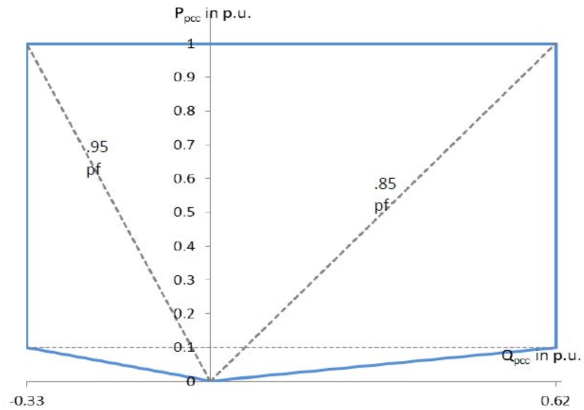

Figure 1: NEPCO Grid Code Power Factor Requirements

The full lagging reactive capability of 0.85 PF must be available between 90%-100% of PCC voltage, and the full leading capability of 0.95 PF must be available between 100% and 110% of PCC voltage.

This reactive capability must also meet a rate of change requirement for step changes in output:

- Step changes from 0 MVAR to either full capacitive (Qmax) or full inductive (Qmin) must be achieved within 5 seconds
- Step changes between (Qmax) and full inductive (Qmin) must be achieved within 10 seconds

B. *Voltage Ride-Through Requirements*

The WPP must remain connected during and immediately after any short circuit event where the positive sequence voltage at the PCC remains above the line shown in Figure 2.

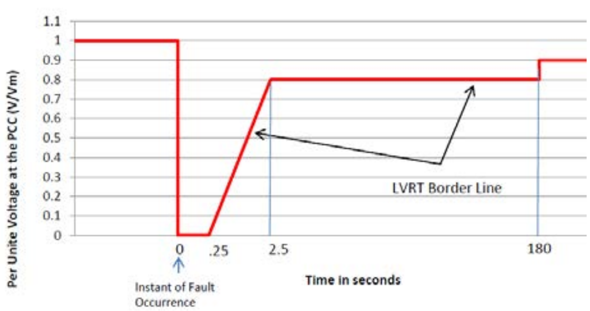

Figure 2: NEPCO LVRT Requirement

The WPP must also remain connected for high voltage events where the positive sequence voltage does not exceed the line shown in Figure 3.

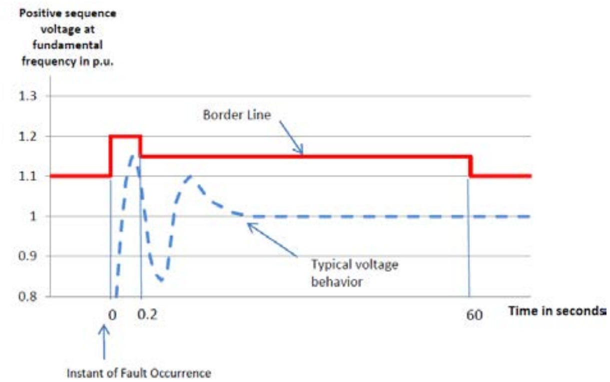

Figure 3: NEPCO HVRT Requirements

C. *Reactive Current Injection Requirements*

The NEPCO Grid Code requires that the wind farm must be designed to supply reactive current during any high- or low- voltage event, as shown in Figure 4. The reactive current requirement is specified at the PCC in terms of ΔIQ, ΔV, and IN, where ΔIQ and ΔV are the change in reactive current and change in voltage and IN is the nominal real current (both measured at the PCC). A ratio of 2% ΔIQ per 1% ΔV is prescribed, with a maximum ΔIQ of 120%.

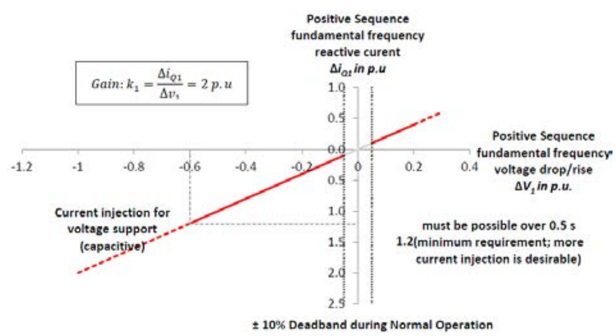

Figure 4: NEPCO Grid Code – Requirements for Reactive Power Support

The reactive power must follow the control characteristic shown in Figure 5, with a rise time of 30ms and a settling time of 60ms.

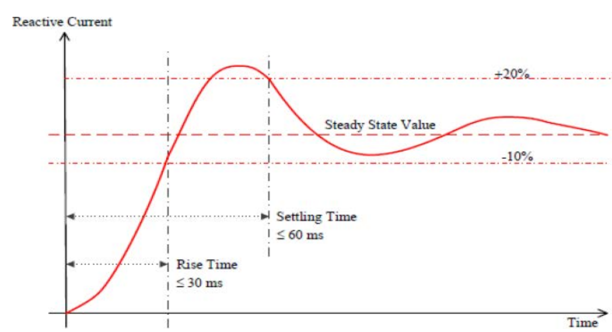

Figure 5: Dynamic IQ Control Characteristic

In the Indian Grid Code, a precise current injection requirement similar to the one described above is not present. Including a similar requirement in a future grid code revision would be beneficial in ensuring adequate reactive power resources can be sized and installed at future Indian wind farms.

III. Example Wind Power Plant

A. *WPP Configuration*

The WPP used for this example is a 45 MW project connecting to the 132kV transmission system. A single line diagram of the project is shown below in Figure *6*.

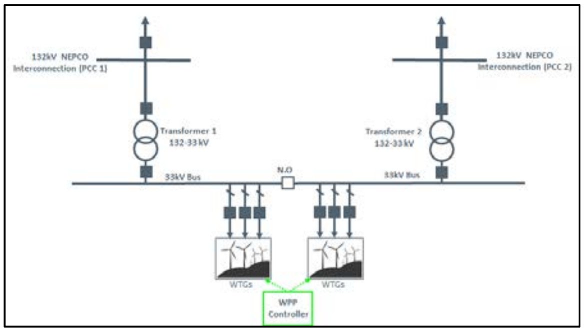

Figure 6: Single Line Diagram, Normal WPP

In addition to the normal operating condition, the WPP must also meet all NEPCO requirements during an N-1 transformer outage (Figure *7*).

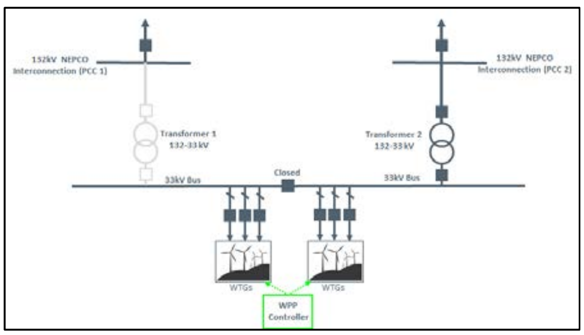

Figure 7: Single Line Diagram, N-1 WPP

B. *WTG Capability*

The wind turbine generators (WTGs) are Type IV full conversion machines, capable of providing reactive power equal to 0.57 p.u. capacitive and 0.45 p.u inductive when at full MW generation (Figure *8*).

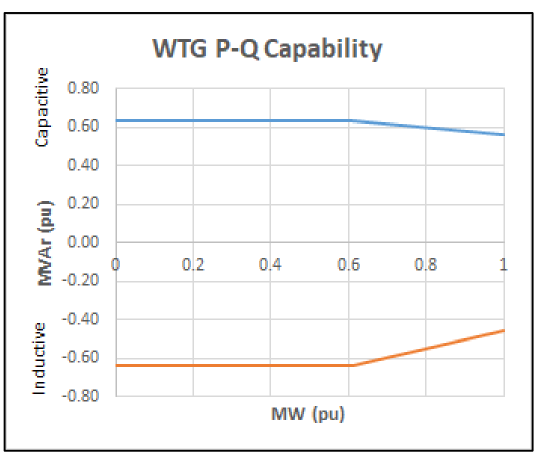

Figure 8: WTG Reactive Power Capability

In addition, they can provide additional reactive current during low- and high- voltage events, up to their maximum current ratings. In this example, the WTGs are set to provide an additional 7% of reactive current per 1% voltage change at their low voltage terminals.

C. *WPP Reactive Power Capability*

The first part of WPP compliance is power flow analysis with varying PCC voltage and WPP MW generation. As there are a normal and N-1 configuration, both must be examined for compliance.

For the normal configuration, as shown in Figure *9*, the WPP does not meet the NEPCO reactive power requirements in Section II.A. The most constrained operating point is at 100% WPP generation, full capacitive power factor, and a PPC voltage of 0.90pu, where the WPP can only achieve PF = 0.924 (or 0.414pu).

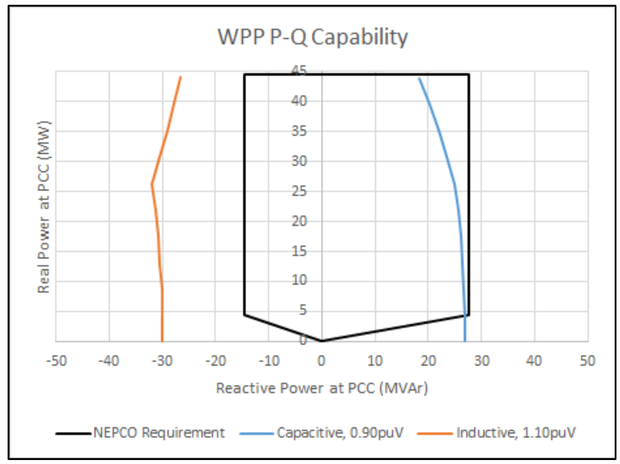

Figure 9: WPP Reactive Power, Normal Configuration

For the N-1 configuration, as shown in Figure *10*, the WPP again does not meet the NEPCO reactive power requirements in Section II.A. The most constrained operating point continues to be at 100% WPP generation, full capacitive power factor, and a PPC voltage of 0.90pu, where the WPP can only achieve PF = 0.939 (or 0.367pu).

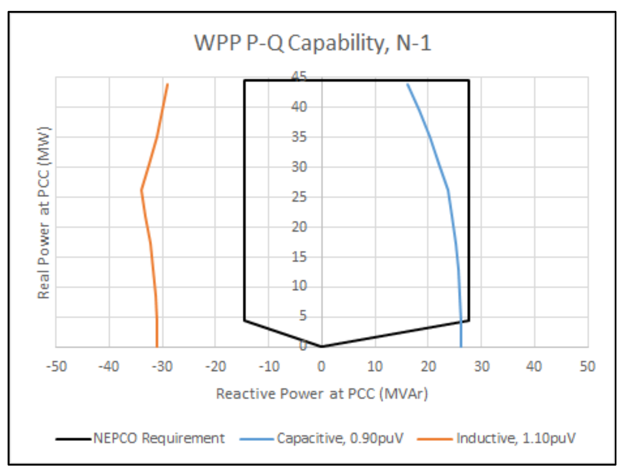

Figure 10: WPP Reactive Power, N-1 Configuration

D. WPP Reactive Current Injection Capability

The next step is to verify the capability of the WPP during faults; its ability to ride through all of the events shown in Figure *2* and Figure *3* and also to provide reactive current support according to Figure *4*. A series of high- and low- voltage events at the PCC are simulated to verify the performance of the WPP, shown in TABLE *1* with the corresponding ΔIQ requirement. The scenarios consider the initial condition of 100% MW and 0 MVAr at the PCC.

TABLE 1: REACTIVE CURRENT INJECTION SCENARIOS

LVRT		
Case #	***Description***	***ΔIQ Requirement***
1	0% Voltage for 250ms	+1.2 p.u
2	20% Voltage for 563ms	+1.2 p.u
3	30% Voltage for 719ms	+1.2 p.u
4	40% Voltage for 875ms	+1.2 p.u
5	50% Voltage for 1031ms	+1.0 p.u
6	60% Voltage for 1188ms	+0.8 p.u
7	70% Voltage for 1344ms	+0.6p.u
8	80% Voltage for 1500ms	+0.4 p.u
9	90% Voltage for 180s	+0.2 p.u
HVRT		
Case #	***Description***	***ΔIQ Requirement***
1	115% V for 60s	-0.3 p.u
2	120% V for 0.2s	-0.4 p.u

The results of each case are shown in Figure *11* for the normal and N-1 configuration, plotted against the NEPCO requirement, and the WPP is deficient in many of the cases.

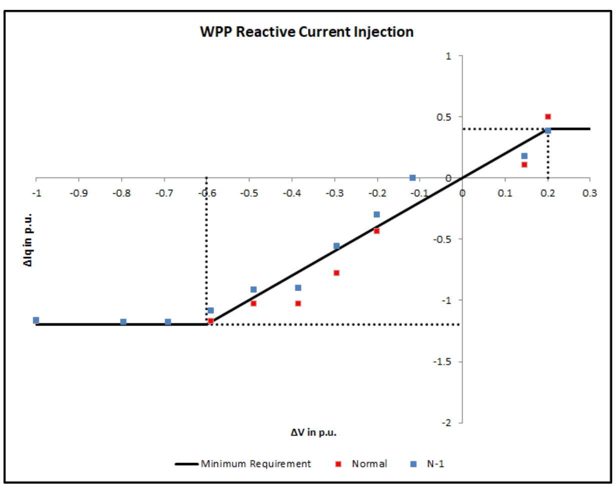

Figure 11: WPP Reactive Current Injection

E. WPP Deficiency

With the results presented in Section C and D, it is clear that additional reactive compensation is needed if the WPP is to comply with the NEPCO requirements. As this additional compensation must be fast-acting (per Sections II.A and II.C), the most effective solution is the use of a Static Synchronous Compensator (STATCOM).

IV. ADDITION OF STATCOM

A. STATCOM Equipment

A STATCOM rated at 16 MVAr is considered for use at this WPP with half of the system (8 MVAr) connected at each MV bus, as shown in Figure *12*.

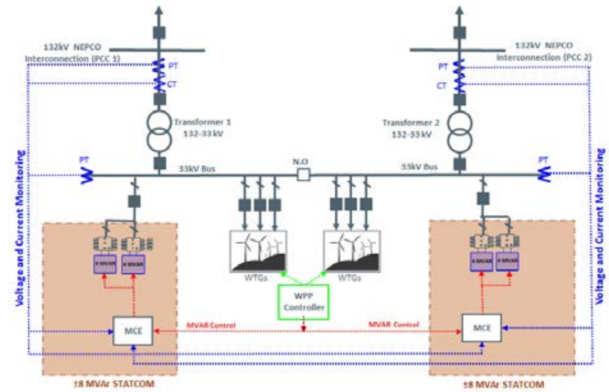

Figure 12: WPP with STATCOM Installed

This STATCOM can also operate in an overload state and provide 3pu rated current for up to 2 seconds (Figure *13*), or a lesser amount of current for a longer duration.

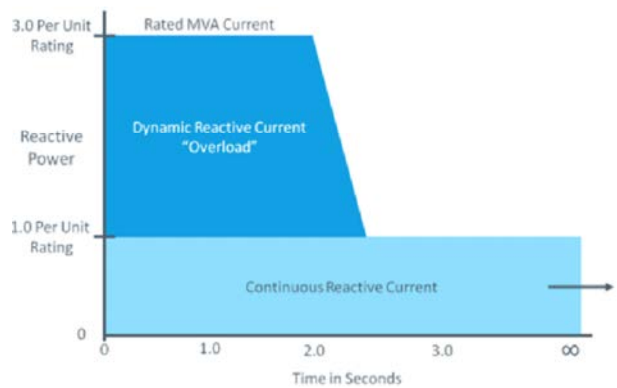

Figure 13: STATCOM Overload Capability

While the PCC voltage remains within the normal operating region of 0.90pu to 1.10pu, the STATCOM operates under control of the central WPP controller and receives reactive power setpoints. During either an LVRT or HVRT event the STATCOM switches to an independent, closed-loop control which measures the PCC voltage and PCC current flow. The goal of this independent control is to make up for any deficiencies in the WPP reactive current during faults and ensure that it remains compliant with the NEPCO requirements.

B. WPP Reactive Power Capability with STATCOM

With the addition of the STATCOM, another power flow analysis, for the same conditions as Section III.C, shows that the WPP is now compliant with the NEPCO reactive power requirements for both the normal and N-1 configurations (Figure *14* and Figure *15*).

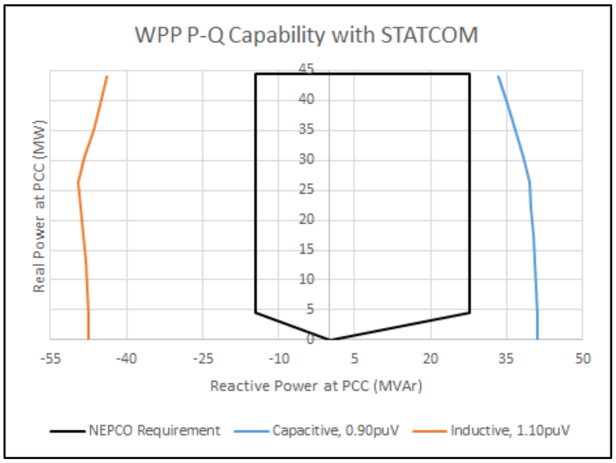

Figure 14: WPP Reactive Power with STATCOM

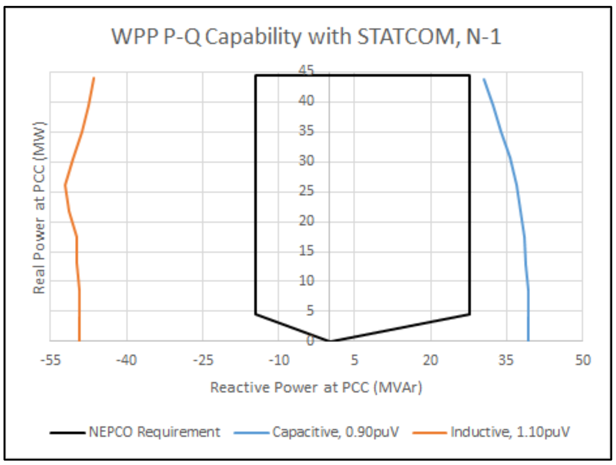

Figure 15: WPP Reactive Power with STATCOM, N-1

C. *WPP Reactive Current Injection Capability*

With the addition of the STATCOM, repeating the LVRT and HVRT analysis with the cases from TABLE *1* shows that the WPP can now provide enough reactive current to meet the NEPCO ΔIQ requirement (Figure *16*)

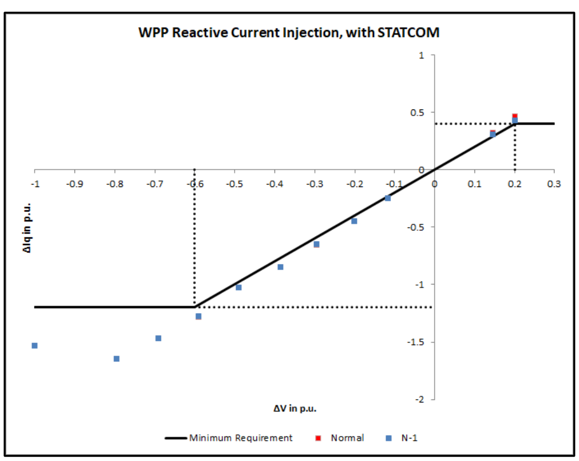

Figure 16: WPP Reactive Current Injection with STATCOM

Looking more closely at the case with 40% remaining PCC voltage, it can also be seen in Figure *17* that the ΔIQ response meets the 30ms rise time requirement from Figure *5*. The top plot shows the PCC voltage dropping from 1.0pu to 0.40pu, while the bottom plot shows the PCC reactive current flow increasing from 0pu to over 1.2pu. The vertical line marks 30ms, at which point the reactive current has already met the required amount.

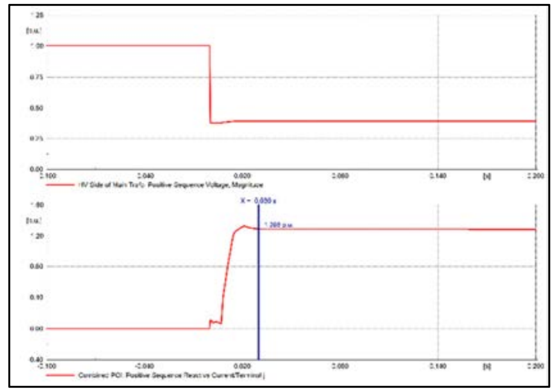

Figure 17: WPP Reactive Current Rise Time

D. *WPP Compliance*

With the installation of a STATCOM to contribute reactive power during normal voltages conditions and regulate the reactive current flow during LVRT and HVRT, the WPP is now compliant with the reactive power and reactive current injection requirements in the Jordan Grid Code.

V. CONCLUSIONS

In this paper the use of a STATCOM to assist a WPP in meeting both reactive power and fast reactive current injection requirements has been examined. As the Indian Grid Code continues to evolve to accommodate higher levels of renewable energy penetration, the need to specify more precise behavior during low voltage events may arise. This paper outlined some approaches that other countries have taken, focusing on reactive current injection during faults, and looked in depth at how a WPP may meet such requirements for a real project.

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