Wind in Weak Grids: 4 Hz or 30 Hz Oscillations?

Lingling Fan, Senior Member, IEEE, Zhixin Miao, Senior Member, IEEE

Abstract—With wind being integrated into weak grids, Texas
sees 4 Hz oscillations while China’s west region sees 30 Hz
oscillations. While both phenomena have been studied and are
claimed to be due to weak grid wind integration, it is valid
to ask this question: What causes the significant difference in
oscillation frequencies? In this letter, we offer an explanation
and provide evidences through dynamic modeling and eigenvalue
analysis. One of the possible reasons is identified as phase-locked-
loop (PLL) parameters. Further, both the low-frequency and
subsynchronous-frequency modes exist at the same time for Type-
4 wind with dc-link voltage control.

Index Terms—Wind; PLL; oscillations

I. INTRODUCTION

W ith wind being integrated into weak grids, Texas sees
4 Hz oscillations [1]. Low-frequency oscillations have
also been observed in high voltage direct current (HVDC)
systems where voltage source converters are connected to a
weak ac grid [2], [3]. In [2], oscillations with frequencies less
than 4 Hz are observed when short circuit ratio (SCR) reaches
1.6. In [3], less than 4 Hz oscillations are identified due to
low SCR. Since 2014, China’s Xinjiang region sees 30 Hz
oscillations [4] due to Type-4 wind integration. The oscillation
frequency can vary from 20 Hz to 40 Hz depending on the
operation condition [4]. This type of oscillation is termed as
subsynchronous frequency oscillation.

While both phenomena have been studied and are claimed
to be due to weak grid wind integration, it is valid to ask this
question: What causes the significant difference in oscillation
frequency?

In this letter, we examined different converter control
assumptions and parameter selections in the literature. We
built analytical models for Type-4 wind with weak grid
interconnection and carried out eigenvalue analysis as well
as dynamic simulation to show the difference in converter
control, particularly PLL parameters, causes the significant
difference in oscillation frequencies.

We found that the low-frequency mode and the
subsynchronous-frequency mode are two different modes
existing at the same time. PLL parameters play a big
role in determining which mode is dominant. Further, the
coon-existence of the two modes will not appear should dc-link
dynamics and dc-link voltage control are not modeled.

II. DYNAMIC MODELS

The study system is shown in Fig. 1. Output power is
assumed at the nominal level or 1 pu and the PCC voltage at
steady-state is 1 pu. Shunt compensation is included to provide
25% nominal level reactive power.

Two types of converter controls will be examined. The
difference lies in whether active power control or dc-link
voltage control is assumed. Investigation on HVDC with weak
grid connection [2], [3] assumes active power control. While
investigation on Type-4 wind weak grid interconnection [4],
[5] assumes dc-link voltage control. [4] indicates that the
dc-link capacitor dynamics is related to the subsynchronous-
frequency mode through participation factor analysis.

Therefore, two dynamic models have been examined: active
power control (Model 1) versus dc-link voltage control (Model
2). For Model 1, dc-link dynamics are ignored. In Model 2,
dc-link dynamics are included. Details regarding Model 1 can
be found in the authors’ prior work [6]. Parameters in [6] are
adopted for this project.

Model 2 includes dc-link dynamics, converter vector con-

ductor, PLL and grid dynamics (shunt capacitor, transmission
line inductor). All dynamics are modeled based on dq-reference
frames so that small-signal analysis is possible. The modeling
block diagram of the system is shown in Fig. 2a

The dc-link dynamics is described as follows.

\[ \frac{CV^2_{\text{base,dc}} dV_{\text{dc}}^2}{2P_{\text{base}}} = P_{\text{wind}} - P_{\text{pu}} \]

where \( P \) is the active power leaving the converter to the grid,
\( P_{\text{wind}} \) is the wind power and treated as a known parameter
in the dynamic model. \( V_{\text{dc}} \) is the dc-link voltage. Superscript
“pu” notates per unit variables. The parameter \( \tau = \frac{CV^2_{\text{base,dc}}}{2P_{\text{base}}} \)
(0.0272) is computed based on the parameters of a 2 MW
Type-4 wind from MATLAB Simscape: nominal dc link
voltage 1100 V, capacitor size 0.09 F. Vector control is adopted
with \( V_{\text{dc}}^2 \) control for the \( d \)-axis control and the PCC voltage
control for the \( q \)-axis control.

III. EIGENVALUE ANALYSIS AND SIMULATION RESULTS

Based on the two dynamic models, four sets of PLL
parameters are examined. The grid reactance \( X_g \) varies from
0.25 pu to 0.59 pu with a step size 0.02 pu. Bode plots of
the closed-loop transfer functions of the PLLs, bandwidths,
parameters are presented in Fig. 2b.

Eigenvalue loci of Model 1 are shown in Fig. 3 while
eigenvalue loci of Model 2 are shown in Fig. 4. Model 1 has
only one mode moving to the right half plane (RHP) when the
grid strength reduces while Model 2 shows two modes moving
to the RHP. Model 1 appears to have more stability margin
compared to Model 1.

Time-domain simulation results of Model 2 are presented
in Fig. 5. A same operating condition is used: \( X_g = 0.55 \text{ pu} \).
Reducing the wind power suppresses the 30 Hz oscillations. For PLL2, 30 Hz oscillations are dominant. The low-frequency and subsynchronous-frequency oscillation modes appear. For PLL1, both modes are damped. For the PLL3 case, both modes have adequate damping. For the PLL4 case, the 40 Hz oscillation mode is dominant and makes the system unstable. Ramping down wind power suppresses the oscillations. The simulation results corroborate with the eigenvalue analysis.

In summary, we successfully demonstrate the co-existence of low-frequency and subsynchronous-frequency oscillation modes. Further, PLL parameters play a big role in determining which mode is dominant.

REFERENCES


