Latest Developments of Negative Sequence Extensions for Generic RMS Models of Wind Turbines

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Latest Developments of Negative Sequence Extensions for Generic RMS Models of Wind Turbines

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***Abstract*—Generic wind turbine models for grid simulation commonly describe balanced grid conditions only. An extension implementing an active control of negative sequence currents for type 3 (DFIG) and type 4 (full converter) wind turbines is presented that could be used to implement the requirements of specific national grid codes (as required for example in Germany).**

The negative sequence control model is used for a distribution grid study to show a possible application for the negative sequence control. The results of simulations are compared to measurements from FRT-tests of a wind turbine during unbalanced faults to show the level of accuracy that can be achieved.

Keywords: wind energy ,generic simulation models, negative sequennce, grid codes

I. INTRODUCTION

Generic models to be used for stability and grid connection studies have been used for many years by the Western Electric Coordinating Council (WECC) Renewable Energy Modeling Task Force in North America. A working group of IEC (TC88 WG27) that includes members of the WECC task force has developed a new generation of generic models in the IEC 61400-27 -1 that have been published in 2015. The focus of these models is the adequate representation of the positive sequence component of power and currents injected into the grid.

Some grid codes also require to address the negative sequence component, especially of the reactive current, to estimate the impact of unbalanced grid faults on turbine stability and the current injection in the grid. Therefore, an optional extension of the positive sequence model of type 3 wind turbines has been proposed by the IEC working group that describes the negative sequence currents caused by the generator and the required reduction of the positive sequence currents during unbalanced faults.

II. APPLICATION OF NEGATIVE SEQUENCE MODELS

A. *Relevance for wind turbines*

The state-of-the-art variable speed wind turbines, i.e. type 3 (DFIG) and type 4 (Full Converter), have proven capabilities to independently control active and reactive currents in positive and negative sequences under unbalanced grid conditions [1]. The main focus of this capability has been so far on minimization of impact of unbalanced voltages on the wind turbine, rather than considering the impact on the grid. For instance in [2] and [3], and [4] negative sequence is controlled to mitigate twice the fundamental frequency oscillations arising in the dc link of the wind turbine back-to-back converters. Similarly in [5], active power and torque oscillations are eliminated via control of negative sequence current in a type 3 wind turbine. However, there are also few studies, where the focus has been on the impact of the wind turbines' asymmetrical fault response on the grid, such as overvoltages and distortion in [6]-[8], and [10]; where in [9] and [11] advanced controls are proposed to maximize utilization of current capacity of the wind turbine for grid support while ensuring to stay in the maximum current limits.

B. Representation in Grid Codes

Although asymmetrical faults in overhead lines of the transmission grid are occurring more frequently as single line-to-ground faults with 70%, line-to-line faults with 15%, double line-to-ground faults with 10%, than symmetrical faults with 5% occurrences [14], most of the grid codes have omitted requirements for these frequently occurring asymmetrical faults. For instance the European framework for the grid codes, the ENTSO-E RfG has kept the asymmetrical fault requirements as a future development at national level, where it is stated as *"with regard to the supply of fast fault current in case of asymmetrical (1-phase or 2-phase) faults, the relevant system operator in coordination with the relevant TSO shall have the right to specify a requirement for asymmetrical current injection."* and *"Fault-ride-through capabilities in case of asymmetrical faults shall be specified by each TSO"* in [15], which has already been published in the Official Journal of the EU and been a binding EU regulation since 17 May 2016. However, as explored in [6]-[8], the negative sequence response of wind turbines during asymmetrical faults impact the grid in terms of overvoltages at the non-faulty phases, further distortion of the balance of the voltages, and secure operation of the protection system, especially with high share of wind power. Hence special requirements for asymmetrical fault response are starting to appear in the new grid codes, for instance new German grid codes for high voltage[12] and medium voltage [13].

III. NEGATIVE SEQUENCE MODELS

A. Doubly Fed Generator - Type 3

Wind turbines with a doubly fed generator system are coupled to the grid very closely since the stator of the generator is connected directly to the grid. In the case of sudden voltage unbalances, the generator responds with a negative sequence reactive current that limits the voltage unbalance – comparable to a synchronous generator. Although this behavior may be favorable for the grid, it can lead to high currents that could limit the capability of a turbine to provide positive sequence reactive current as required by the grid code or to undesired mechanical resonances. [5]. Many turbines with DFIG therefore have a negative sequence current control that tries to limit the negative sequence currents to a certain degree.

The structure of a model extension for positive sequence simulation models of a DIFG as proposed for IEC 61400-27-1 is shown in Figure 1.

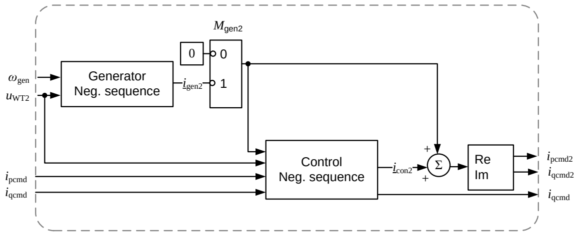

Figure 2. Comparison of measurements (red solid line) and simulation results (blue dashed line) for the positive sequence.

The negative sequence control and limitation model is shown in Figure 2, the corresponding limitation block in Figure 3.

B. Full Converter – Type 4

The implementation for Type 4 can be considered a special case of the structure described for Type 3, with the generator negative sequence current *igen2* set to zero.

Type 4 WT do not usually need a specific controller to eliminate the injection of negative sequence current. On the contrary, if such contribution is desired, it must be explicitly provided. One possible way to define that contribution is with a proportionally factor relative to the negative sequence voltage deviation, similar to existing approaches for the positive sequence. Figure 2 illustrates such implementation, where the path of K_{Qv2} represents a negative voltage control which could be used for Type 4. In this case, since a full converter is used, input *igen2* should be zero. The outputs of this block are the negative sequence phasor and the positive sequence reactive current, which will be forwarded respectively to the generator and current limiter models.

The negative sequence reactive current limitation is presented in Figure 3. In case of Type 4 the parameter *iq2maxi* can be set to zero. With *Mqlim2* set to zero it is possible to assign lower priority to the negative sequence current compensation compared to the positive

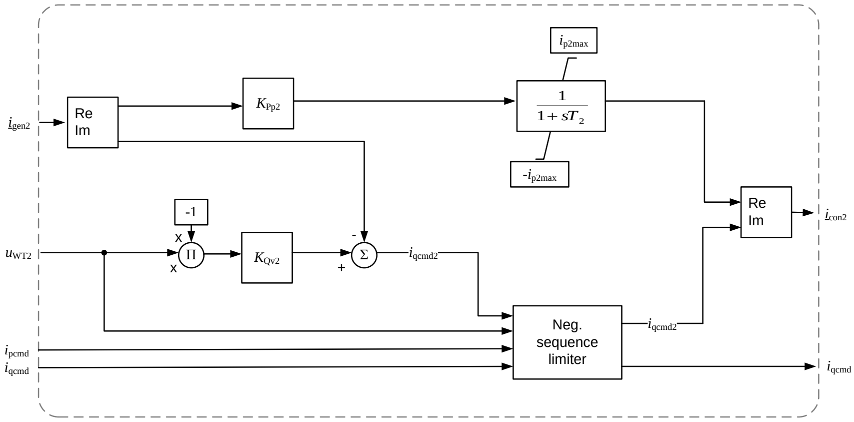

Figure 1. Block diagram of negative sequence reactive current conntrol and limitation model for Type 3 and Type 4.

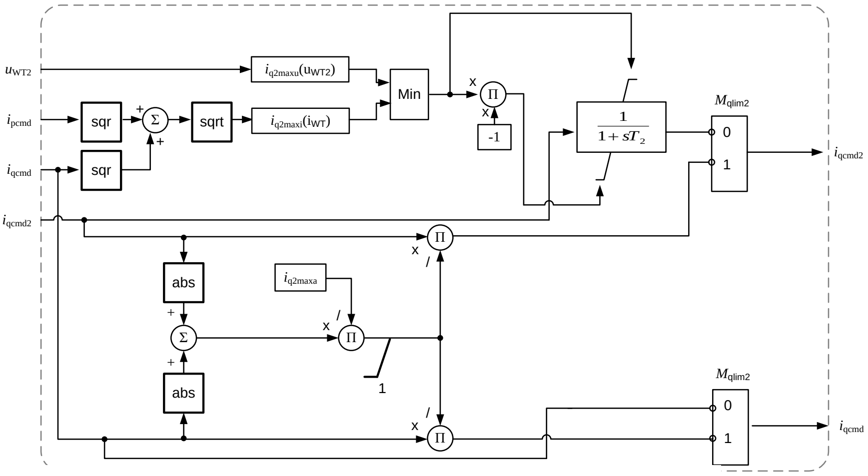

Figure 3. Block diagram of the negative sequence reactive current limiter model for Type 3 and Type 4.

sequence current output. With *Mqlim2* set to one, positive and negative sequence reactive current can both be limited.

IV. APPLICATION ON DISTRIBUTION NETWORK

Distribution networks are generally designed to support asymmetric loads and feed in. This fact leads to asymmetric load flows, which can be supervised using the unbalance factor. Asymmetric load flows result in higher loadings and losses in single phases and transformer windings and are therefore not welcome. In networks with a high number of asymmetric loads and/or elements with less than 3 phases, the installation of wind turbines and other type of renewable generation can contribute to improve unbalance voltages and power quality in general, either in normal or emergency operation.

The example illustrates how the power quality of a distribution network can be improved. The distribution network contains elements like Loads, Transformers, Lines, PV-System (1P) and Switch gears with different number of phases.

The distribution network is presented in Figure 5 Operating voltages are 11kV and 33kV, and the network is connected to a 132kV transmission system. Different low voltage busbars with different phase, neutral and neutral to ground technologies are represented (400V, 415V, 460V and 690V). The total load in the system is 5.491 MVA.

A three phase full converter wind turbine rated 2MVA is added to the main busbar of the 11kV distribution network. The IEC Type 4A wind turbine model is modified to add a negative sequence voltage controller, regulating the negative sequence current delivered to the grid through a PI controller.

A negative sequence voltage reference step is provided at t=2s, with the scope of reducing the negative sequence voltage u2 at LV terminals of the wind turbine inverter from 1.4% to a level of 1%.

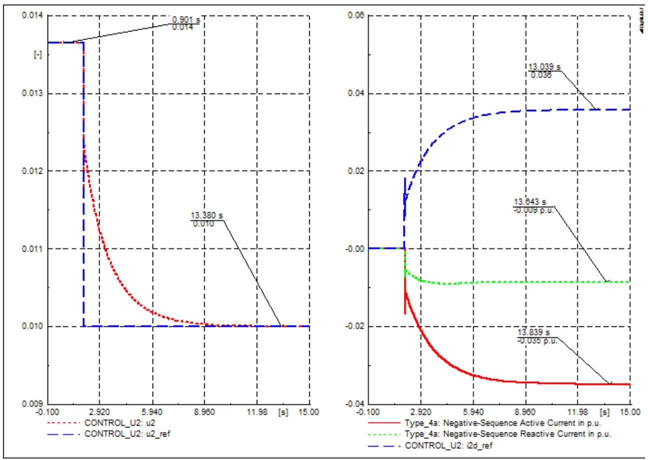

Figure 4. On the left, negative sequence voltage reference reduction at t=2s (u2_ref) and response of the measured negative sequence voltage (u2) at LV side of the inverter. On the right side, the negative sequence d-axis reference current (i2d_ref) at the inverter and the measured active and reactive negative sequence current (i2P, i2Q) at the inverter.

The response of the negative sequence voltage controller is shown in Figure 4. The u2 setpoint step is applied as a parameter event at t=2s and the negative sequence voltage is reduced from 1.4% to 1% (left side). The impact is a higher unbalanced current, as shown on its negative sequence response (right side).

V. MODEL VALIDATION

The type 4 model has been validated in Matlab/Simulink by comparing measurements and simulations performed with a playback approach. The measurements were obtained from field tests as described in [16], [17]. Positive and negative sequence components were then calculated for the voltage and current by applying [18]. The voltages were fed to the model and the output currents compared. Figure 6 and Figure 7 show the obtained results for a solid two-phase to

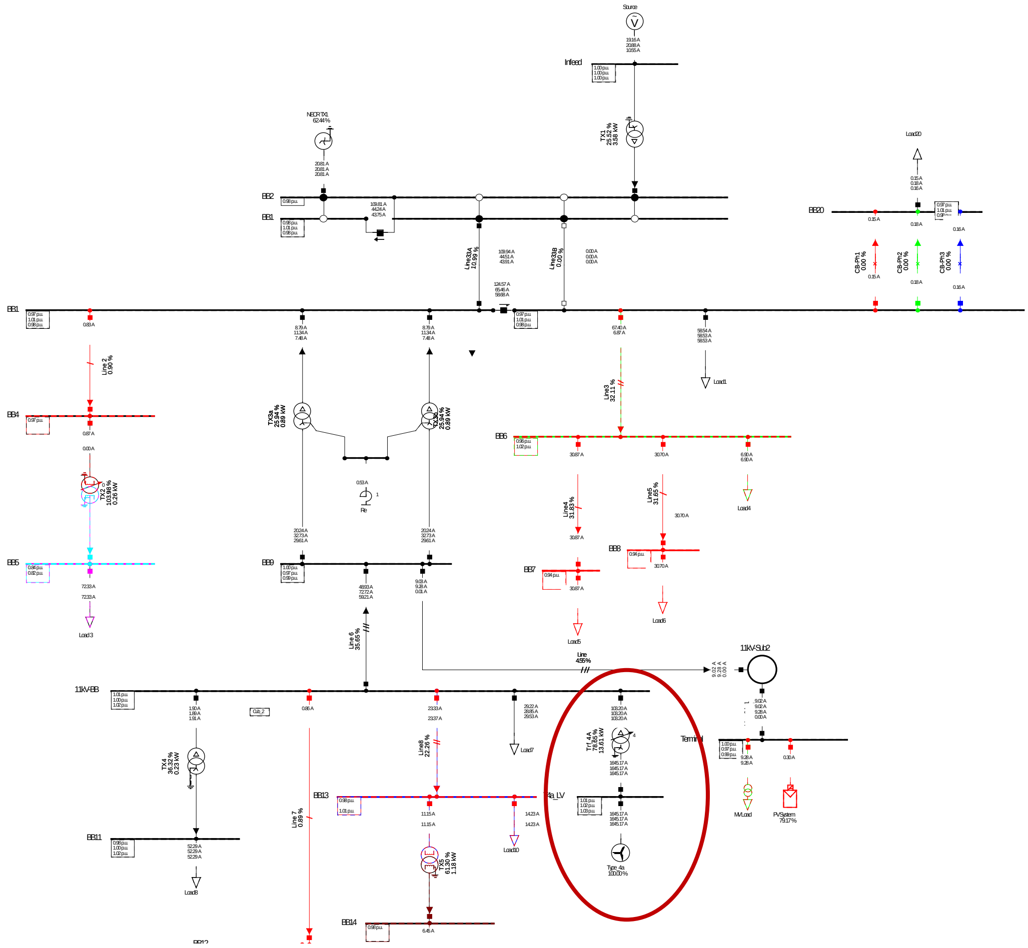

Figure 5. Unbalanced distribution network.

ground fault. K_{qv} and K_{Qv2} are both equal to 2. The model was parameterized with *Mqlim2* = 1 and *iq2maxa* = 1.38.

In general, the results show a very good correspondence between measurements and model. Small deviations can be detected in the positive sequence reactive current after switching the series reactance at t=1s, and in the negative sequence active current during fault. The former is due to a specific controller used in Germany that has not been built in the generic model. The latter can be attributed to the grid filter not modelled in the simulation. In both cases, the deviations are not considered significant.

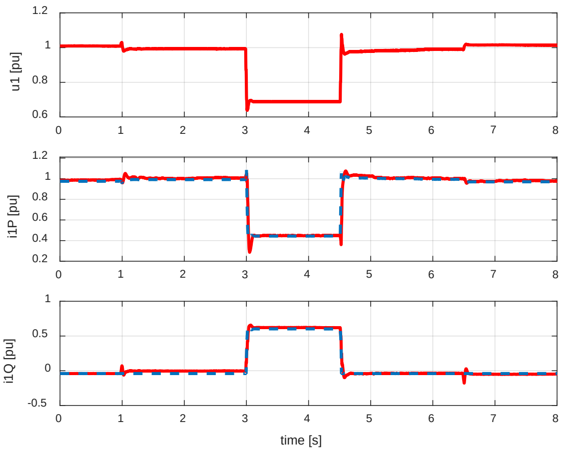

Figure 6. Comparison of measurements (red solid line) and simulation results (blue dashed line) for the positive sequence

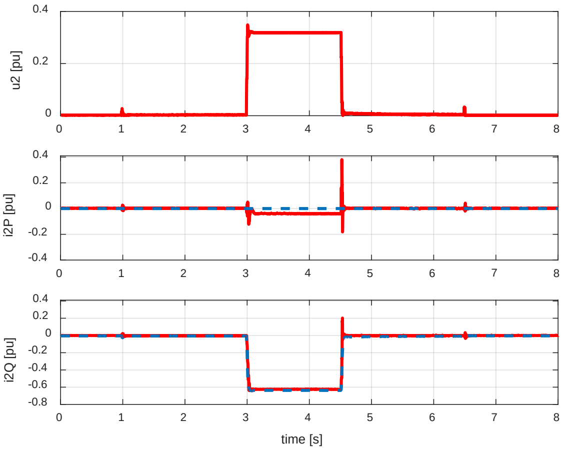

Figure 7. Comparison of measurements (red solid line) and simulation results (blue dashed line) for the negative sequence

VI. CONCLUSION

A negative sequence current limitation and control extension for generic wind turbine simulations models has been presented. The comparison to measurements shows a good level of accuracy. An application to a distribution grid shows the capability of the control to reduce voltage unbalances in the grid.

A model has been shown that can be used to extend existing type 3 and type 4 generic models based on IEC 61400-27 and WECC descriptions with the capability to respond to negative sequence voltages as required by some grid codes now.

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