Compatibility of IEC 61400-27-1 Ed 1 and WECC 2nd Generation Wind Turbine Models

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***Abstract*—The IEC TC88 WG27 and the Western Electric Coordinating Council (WECC) Renewable Energy Modeling Task Force, in North America, have been developing the IEC 61400-27-1 and WECC 2nd Generation Wind Turbine generic electrical models, where the first editions are published in 2014 and 2013, respectively. Although the two working groups have been collaborating closely, there are small differences between the approaches of the two modelling standards, especially in terms of parameter sets and complexities for different functions. In this paper, compatibility of the IEC and WECC wind turbine models has been investigated, via pointing out the common parts and small discrepancies. It is shown that via parametrizing accordingly, similar responses can be obtained from both of the models and both models can be utilized well to represent the real wind turbines. The compatibility is shown via model to model comparison of the IEC and WECC wind turbines' simulation results for the wind turbine types 3 and 4, which are the most common technologies. Additionally, detailed behavior of the IEC type 3 model during voltage drop and recovery are compared against measurements.**

Keywords-component; Wind turbine generators, wind power plants, wind energy integration, power system simulation, power system modeling, IEC standards

I. INTRODUCTION

Wind turbine technologies are highly complex generation equipment. There is a need, as with all power equipment, to have a hierarchy of models for the simulation of such technologies for a variety of power system studies. Thus, detailed vendor specific models are needed, as well as electromagnetic transient (EMT) level vendor specific models. However, such models are often too complex to include in large scale studies, such as when performing simulations of continental Europe or the North American power system. Furthermore, vendor specific models often contain proprietary details that cannot be shared publicly and are released to utilities under non-disclosure agreements. This makes it impossible to share such models with reliability entities as required for example in North America. Thus, there is a clear need for simplified, non-property, public and standard models for simulating wind power technologies in large scale power system stability studies. Such models are referred to as generic model structures.

The Western Electric Coordinating Council (WECC) Renewable Energy Modeling Task Force (REMTF), in North America, developed a set of generic renewable energy system models for modeling wind generation, photovoltaic (PV) generation and battery energy storage [1], [2] and [3]. These models have been implemented in Siemens PTI PSS®E, GE PSLF™, PowerWorld Simulator, PowerTech Labs, and recently in DIgSILENT PowerFactory software. In addition, a user's guide has been developed for these models [4] and the model specifications also made publicly available [5], [6], [7] and [8]. These models have intentionally been developed in a modular format (as with the IEC models) to ensure that they can be easily augmented and refined as the technology and modeling techniques continues to advance.

The first edition of IEC 61400-27-1 was published in February 2015 [9], which specifies wind turbine models and validation procedures. IEC 61400-27-1 includes some additional options which are not part of the WECC models, mainly to enable wind turbine manufacturers to meet European TSO requirements for model validation [10]. Examples of such extensions are the aerodynamic model developed by Fortmann [11] and the active crowbar representation in type 3B developed by Buendia [12]. The IEC 61400-27-1 models have already been implemented and published in the latest version of DIgSILENT Power Factory and included in the coordination work by the ENTSO-E as part of the Common Grid Model Exchange Standard (CGMES).

In order to verify performance of these models in terms of adequate representation of the real wind turbine (WT) or wind power plant (WPP) behavior, validation studies have been performed both for WECC and IEC models. In [14], the WECC type 3 model is validated against two vendors' (ABB, Vestas) WT measurement data, while in [15] the WECC type 4 model is validated against four vendor's (ABB, Vestas, Siemens, Enercon) WT measurement data. In [16], validation results for the WECC and vendor specific models are given based on field or factory test measurements both at WT and WPP level. In [17], the IEC type 4B model is compared against WT measurements and in a recent study [18], the IEC type 3 model is validated at the WPP level against WPP field measurement data.

The first edition IEC models are very similar to the 2nd generation WECC models [5], since the two groups have closely collaborated from the beginning of the establishment of the IEC group. The intention – although not completely fulfilled – was to make the IEC models compatible with the WECC models. The compatibility of the IEC models with the WECC models is supported by the modular structure of the models [10]. However, compatibility of these two has never been studied before, which is accomplished for the first time in this paper. In the following pages, dynamic response of the WECC models during certain grid events (low voltage faults) are identified and captured by the IEC models via tuning the IEC models, while showing how the parameter sets can be adapted between the two modelling references.

II. IEC AND WECC TYPE 3 AND TYPE 4 MODELS

As explained above, both the IEC and WECC models have been developed to be generic in order to minimize confidentiality issues, and with adequate complexity to capture sufficient dynamics of the wind turbines, while being computationally efficient to be implemented in large scale power system studies. These model are thus emulations of the wind turbines and thus the model parameters do not necessarily have a one to one exact correspondence to physical parameters in any vendor's equipment. Both of the modelling references include the industry-standard wind turbine types; as types 1 to 4, which can be configured and parametrized to represent the response of real wind turbines. In this section, today's most common types, i.e. type 3 and type 4 WT models, from the IEC and WECC are briefly presented, which are also utilized for compatibility simulations in the next section.

The IEC type 3 model as shown with its general structure in Fig. 1, which includes specific aerodynamic and pitch control models, is considered to be very similar to the WECC type 3 model in Fig. 3. In the IEC standard, type 3 has been classified as 3A and 3B based on the generator sets; without crowbar and with crowbar, respectively. The IEC type 4B model in Fig. 2 with a mechanical (two-mass) model corresponds to the WECC type 4A model in Fig. 4 (with Drive-Train block). Both references has type 4 models without the mechanical parts, as IEC type 4A and WECC type 4B. One of the main structural differences is that the IEC has specific active power (P) control blocks for each of the type 3, 4A, and 4B; whereas the WECC has the common control block, reec_a, which is used in type 3, 4A and 4B. Both IEC and WECC have developed WPP controllers, which send active power and selective reactive power or voltage setpoints to the WT controllers [19]. At the WT level and as cascaded by the outer WPP controller, both of the modeling references have the following q control schemes;

- Voltage control at the WT level (Closed loop)
- Reactive power control at the WT level (Closed loop with inner voltage control)
- Power factor control at the WT level (Closed loop)
- Open loop reactive power control at the WT level
- Open loop power factor control at the WT level
- Voltage control at the WPP level
- Reactive power control at the WPP level
- Power factor control at the WPP level

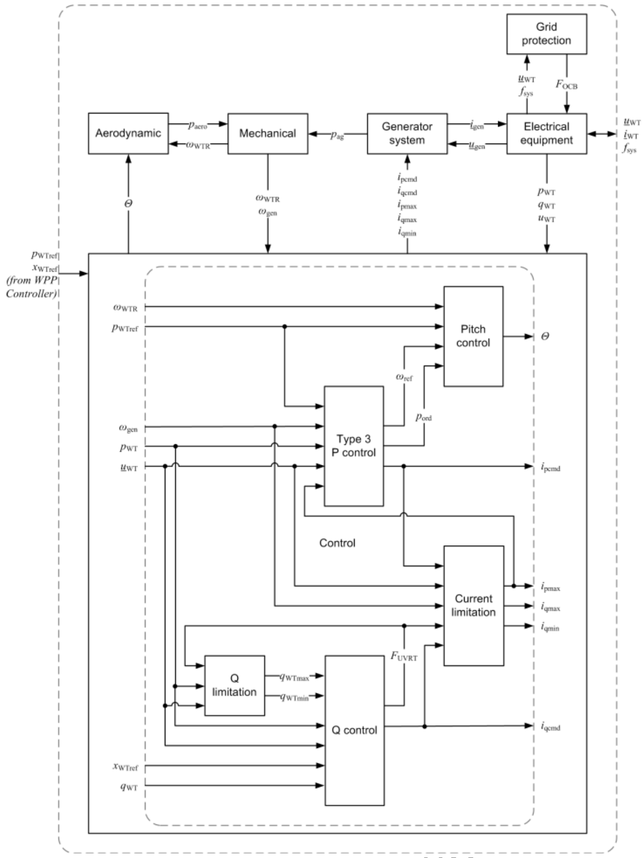

Figure 1. IEC type 3 WT model [9]

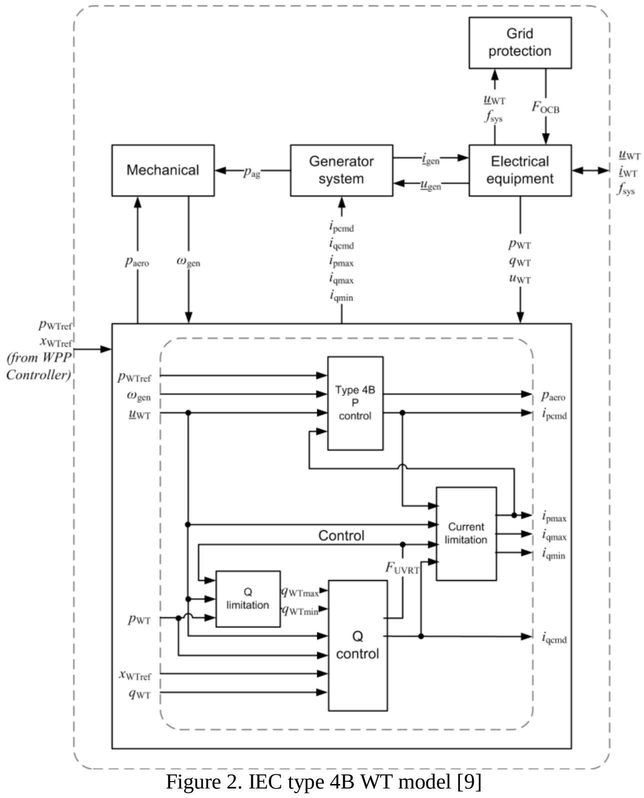

Figure 2. IEC type 4B WT model [9]

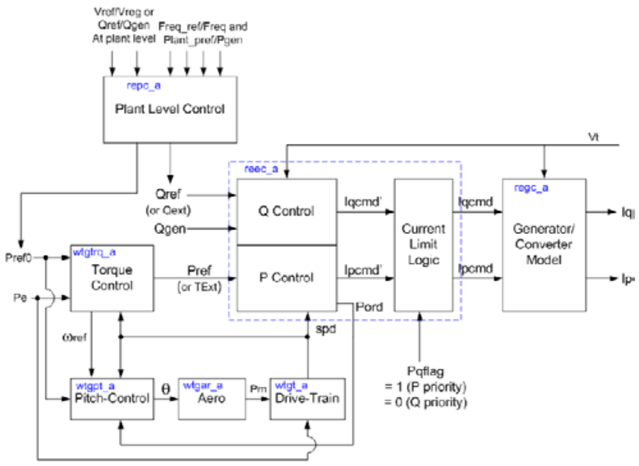

Figure 3. WECC Type 3 model [5]

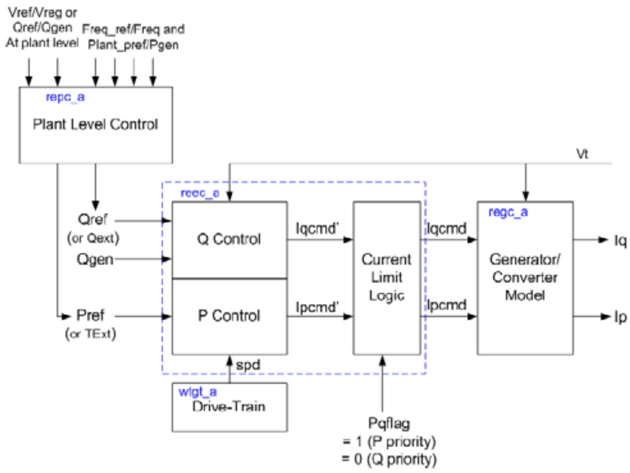

Figure 4. WECC Type 4A model [5]

III. COMPARISON VIA SIMULATION

In this section the IEC type 3, 4A, and 4B models are compared against the WECC type 3, 4B, and 4A models, respectively. The simulation results here, for the IEC models are implemented in DIgSILENT PowerFactory, whereas the WECC in GE PSLF^{TM}, whose parameters are given in spread-sheet of [13]. The IEC models are tuned against the WECC models in order to capture them, and the mapping of each parameter between the two references is shown in the appendix. As expected for some of the IEC parameters, corresponding WECC parameter do not exist. For these parameters some generic values, which were available in the IEC working group, are used. The two models are compared for the fault case in the test case system in Fig. 5, with a three-phase fault at bus-4, resulting in 0.5 pu voltage dip at the WT low voltage terminal for 1 second.

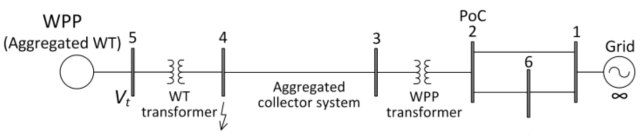

Figure 5. Simple test case system. The model is adopted from [13]

A. *Type 3 Comparison (WECC type 3 & IEC type 3A)*

As observed in Fig. 6 -8, there are some discrepancies between the IEC and WECC type 3 results. This is believed to be due to three main reasons; absence of stator current limit in the WECC models, slightly different generator/converter model for the IEC model, which includes elementary representation of stator dynamics, and finally the active drive train damping block of the IEC type 3 that is not modelled in this version of the WECC type 3. However, it should be noted that the damping in IEC type 3 is deactivated via setting the "K_{DTD}" parameter to zero, as given in the appendix. There is still a need for an explanation for the apparent slight difference in the damping and level of the torsional oscillations post fault, which the authors are still working on.

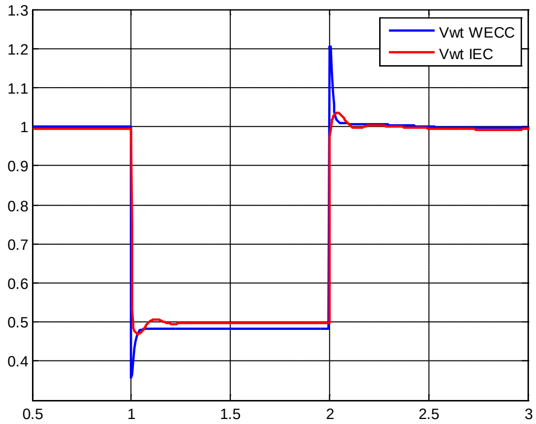

Figure 6. WT voltage for type 3 [pu] vs time [s]

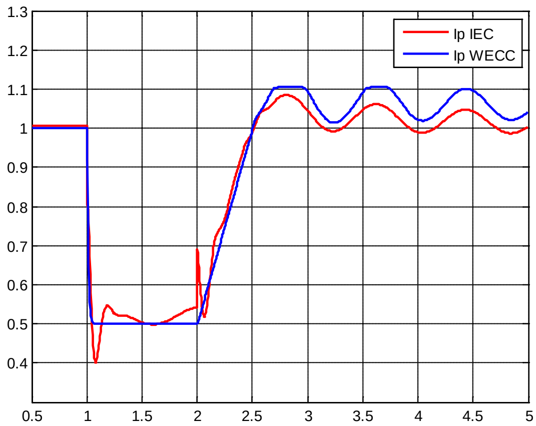

Figure 7. WT Active Current Actual Values for type 3 [pu] vs time [s]

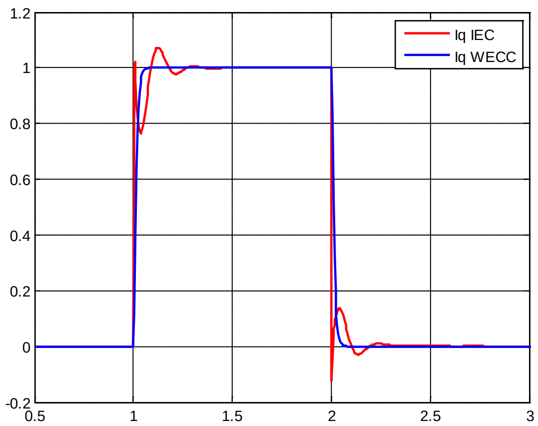

Figure 8. WT Reactive Current Actual Values for type 3 [pu] vs time [s]

B. IEC Type 3 and WECC Type 3 - Comparison with Measurements

The type 3 models of IEC and WECC show differences at voltage drop and voltage recovery (Fig. 6) due to different reactive currents of the two models (Fig. 8). These differences are due to a simpler generator model of the WECC models. While the WECC type 3 model is based on an ideal current source, the IEC model contains a real current source with parallel impedance that can represent the dominant parts of the rotor dynamics of a type 3 generator.

A comparison of the IEC type 3 model with measurements of a 2 MW wind turbine during field tests is shown in Fig. 9 (voltage drop instant) and Fig. 10 (voltage recovery instant). It is visible that the IEC type 3 model is able to represent the reactive current dynamics during the voltage drop and the voltage recovery very well. As a result of fast reactive current response following voltage changes, the type 3 turbine does not cause voltage spikes during voltage drop (at t=1s) and voltage recovery (at t=2s). The results of the WECC type 3 model could trigger a voltage protection at t=2s event though a real turbine would not cause such a spike.

Differences visible in voltage and reactive current between Fig. 6 and Fig. 8 on one side and Fig. 9 and Fig. 10 on the other side are due to a filtering needed to be able to compare simulations to positive sequence values of measurements [9].

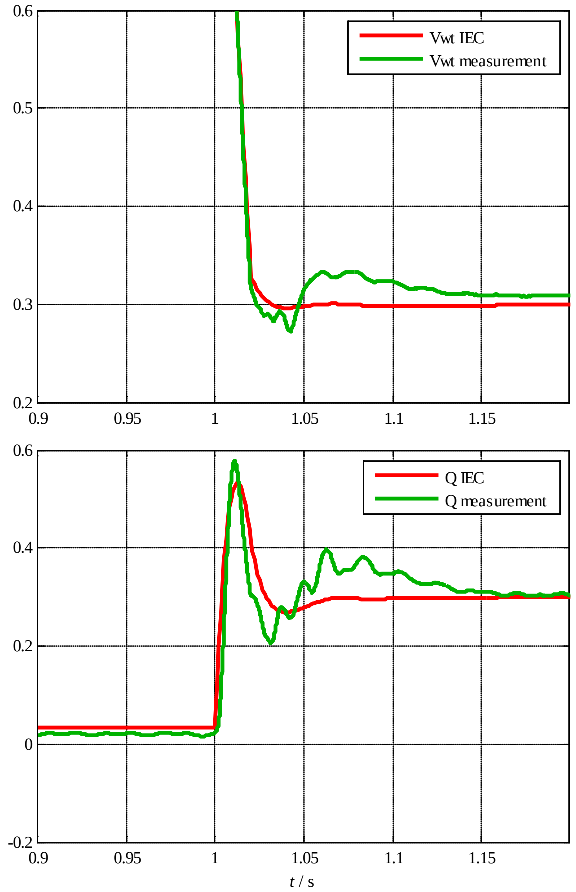

Figure 9. WT Voltage and Reactive Power for type 3 [pu] vs time [s], comparison of model and measurement (voltage drop).

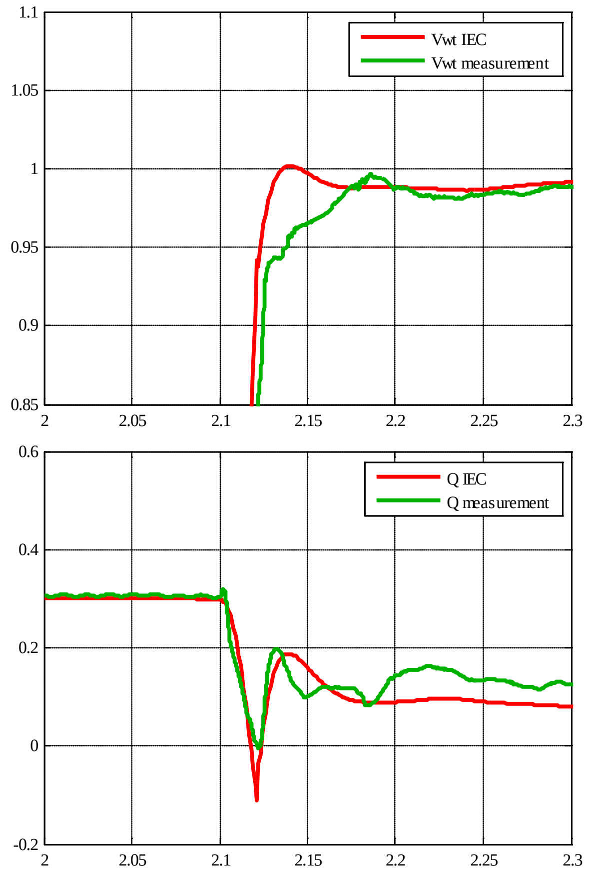

Figure 10. WT Voltage and Reactive Power for type 3 [pu] vs time [s], comparison of model and measurement (voltage recovery).

C. IEC Type 4A and WECC Type 4B Comparison

The type 4 models without the mechanical model are compared in Fig. 11-13. It is observed that the two models match each other with a large extent, which is a good example that the IEC and WECC models are ideally compatible for the types and fault case shown here.

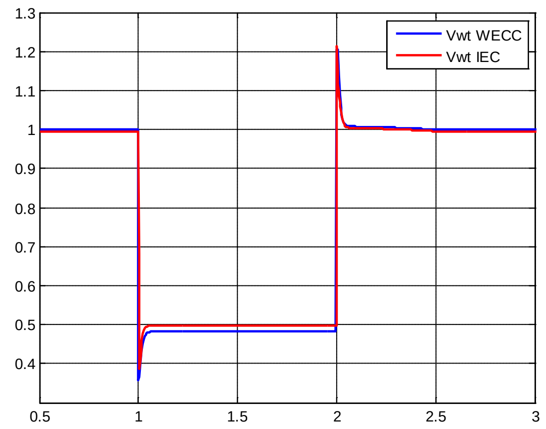

Figure 11. WT voltage for type 4 w/o mechanical [pu] vs time [s]

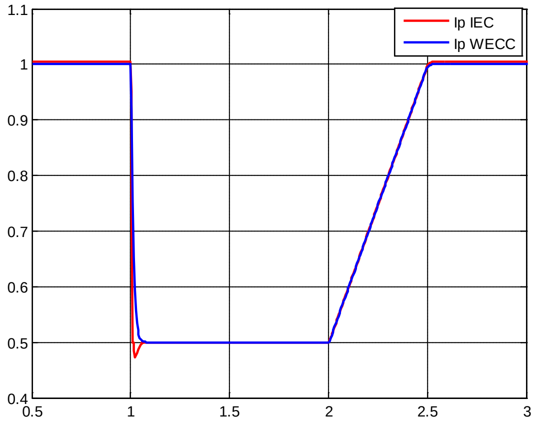

Figure 12. WT Active Current Actual Values for type 4 w/o mechanical [pu] vs time [s]

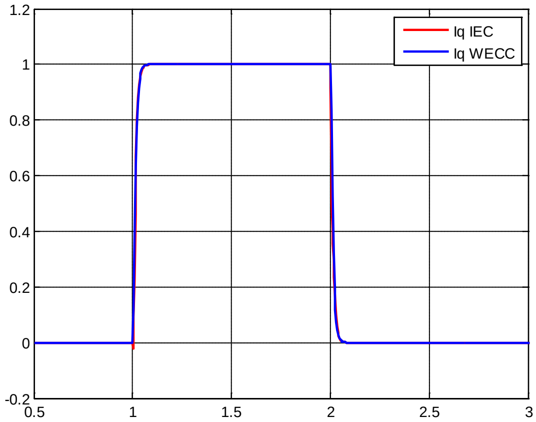

Figure 13. WT Reactive Current Actual Values for type 4 w/o mechanical [pu] vs time [s]

D. . IEC Type 4B and WECC Type 4A Comparison

The type 4 models with a mechanical (two-mass) models show almost perfect match as seen in Fig. 14-16 below, which is another good example that the IEC and WECC models are ideally compatible for the types and fault case shown here.

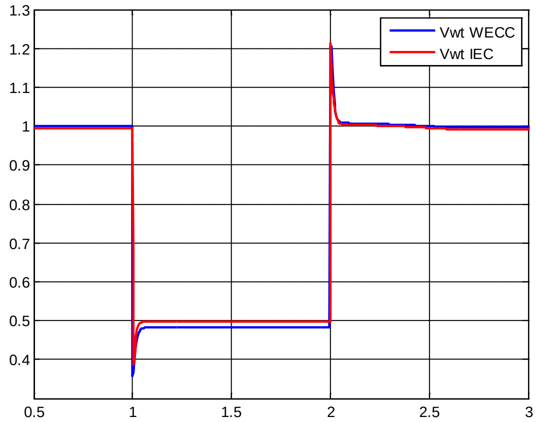

Figure 14. WT voltage for type 4 with mechanical [pu] vs time [s]

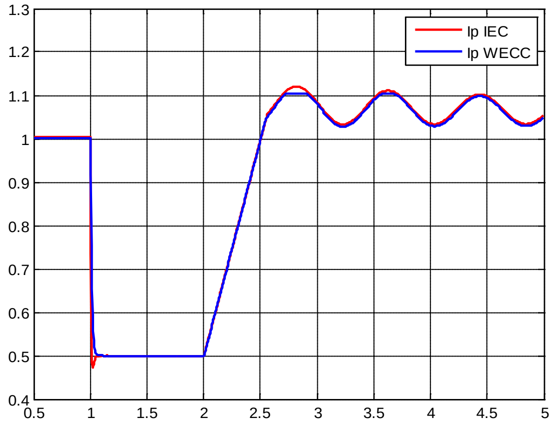

Figure 15.WT Active Current Actual Values for type 4 with mechanical [pu] vs time [s]

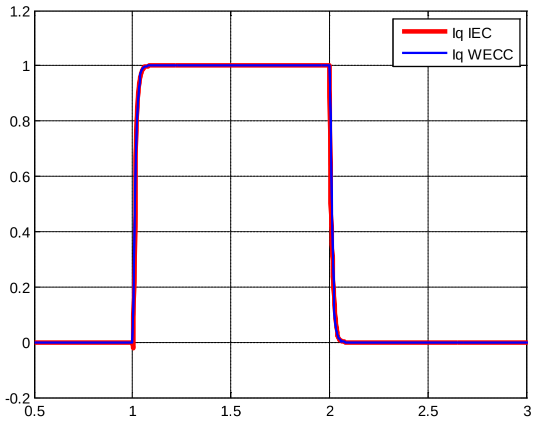

Figure 16. WT Reactive Current Actual Values for type 4 with mechanical [pu] vs time [s]

IV. Future Work and Conclusion

In this paper, the two wind turbine electrical modeling references, WECC 2nd Generation and IEC 61400-27-1 are investigated in terms of their compatibility. It is shown that the two can represent each other up to a large extent, for the studied moderately severe (0.5 pu voltage dip) fault case. Small discrepancies, which can be acceptable within large area power system studies, are still being analyzed in detail by the authors. However, there is still need for further comparative studies, for instance response to a setpoint (voltage or reactive power) change. Additionally, the WPP control models need to be compared in order to see the compatibility, which has been the intention during the recent development periods. Moreover, investigation of the implementation of the models on different platforms in terms of computation speed stands as a future work too.

V. Appendix

Parameters that are adopted from the WECC models into the IEC models are shown in the tables below. In the cases where a corresponding parameter name is not given for the WECC, generic values are used for the IEC model.

TABLE I. PARAMETER LIST FOR CURRENT LIMITER MODEL

WECC	IEC	WECC 4B IEC 4A	WECC 4A IEC 4B	WECC 3 IEC 3A
imax	i_{max}	1,3	1,3	1,3
imax	i_{maxdip}	1,3	1,3	1,3
-	M_{DFSLim}	1	1	1
Pqflag	[a] M_{qpri}	0	1	1
vp1	$I_{pmax}(u_{WT})$	0,7	0,7	0,7
ip1		0,5	0,5	0,5
vp2		0,75	0,75	0,75
ip2		0,6	0,6	0,6
vp3		0,9	0,9	0,9
ip3		1,3	1,3	1,3
vp4		1	1	1
ip4		1,3	1,3	1,3
vq1	$I_{qmax}(u_{WT})$	0	0	0
iq1		1	1	1
vq2		0,1	0,1	0,1
iq2		1	1	1
vq3		0,5	0,5	0,5
iq3		1	1	1
vq4		1	1	1
iq4		1	1	1
trv	$T_{ufiltcl}$	0,01	0,01	0,01
vup	u_{pqumax}	1,1	1,1	1,1
-	K_{pqu}	2	2	2

a. opposite of WECC. (Mqpri=1: Q priority, Mqpri=0: P priority)

TABLE II. PARAMETER LIST FOR CONSTANT Q LIMITATION MODEL

WECC	IEC	WECC 4B IEC 4A	WECC 4A IEC 4B	WECC 3 IEC 3A
qmax	$qmax$	0,5	0,5	0,5
qmin	$qmin$	-0,5	-0,5	-0,5

TABLE III. PARAMETER LIST FOR P CONTROL MODEL TYPE 4A

WECC	IEC	WECC 4B IEC 4A
trv	$Tufiltp4A$	0,01
tpord	$Tpordp4A$	0,01
dpmax	$dpmaxp4A$	999

TABLE IV. PARAMETER LIST FOR P CONTROL MODEL TYPE 4B

WECC	IEC	WECC 4A IEC 4B
trv	$Tufiltp4B$	0,01
tpord	$Tpordp4B$	0,01
-	$Tpaero$	0,01
dpmax	$dpmaxp4B$	999

TABLE V. PARAMETER LIST FOR P CONTROL MODEL TYPE 3

WECC	IEC	WECC 3 (IEC 3A)
-	$\omega offset$	0.05
p1	$\omega(p)$	0,2
spd1		0,58
p2		0,4
spd2		0,72
p3		0,6
spd3		0,86
p4		0,8
spd4		1
kpp	KPp	0,5 (2)
kip	KIp	1 (10)
tp	$Tpfiltp3$	0,01
trv	$Tufiltp3$	0,01
twref	$T\omega ref$	60
-	$T\omega filtp3$	0.05
-	$KDTD$	0
-	$pDTDmax$	0.15
-	ζ	0.5
-	ωDTD	11.3
tpord	$Tpord$	0,01
dpmax	$dpmax$	999
-	$dprefmax$	0.3
-	$dprefmin$	-0.3
vdip	$updip$	0,9
-	$d\tau max$	10
temin	$\tau emin$	0
-	$\tau uscale$	1
-	$MpUVRT$	1
-	$d\tau maxUVRT$	0
vdip	$uDVS$	0,9
thld2	$TDVS$	0

TABLE VI. PARAMETER LIST FOR PITCH ANGLE CONTROL MODEL

WECC	IEC	WECC 3 IEC 3A
kpw	$KP\omega$	150
kiw	$KI\omega$	20
kpc	KPc	0
kic	KIc	0
kcc	KPX	0
pimax	Θmax	30
pimin	Θmin	0
piratmx	$d\Theta max$	10
piratmn	$d\Theta min$	-10
tpi	$T\Theta$	0,01

TABLE VII. PARAMETER LIST FOR Q CONTROL MODEL

WECC	IEC	WECC 4B IEC 4A	WECC 4A IEC 4B	WECC 3 IEC 3A
pfflag *vflag* *qflag*	*MqG*	2	2	4
thld	*MqUVRT*	0	0	0
trv	*Tufiltq*	0,01	0,01	0,01
tp	*Tpfiltq*	0,01	0,01	0,01
kqp	*KPq*	1	1	1
kqi	*KIq*	5	5	5
Kvp	*KPu*	1	1	1
kvi	*KIu*	5	5	5
dbd1	*udb1*	-0,1	-0,1	-0,1
dbd2	*udb2*	0,1	0,1	0,1
kqv	*Kqv*	3	3	3
vmax	*umax*	1,1	1,1	1,1
vmin	*umin*	0,9	0,9	0,9
vref1	*uref0*	0	0	0
vdip	*uqdip*	0,9	0,9	0,9
tiq	*Tqord*	0,01	0,01	0,01
thld	*Tpost*	0	0	0
iqh1	*iqmax*	1	1	1
iql1	*iqmin*	-1	-1	-1
iqh1	*iqh1*	1	1	1
iqfrz	*iqpost*	0	0	0
-	*rdroop*	0	0	0
-	*xdroop*	0	0	0

TABLE VIII. PARAMETER LIST FOR TWO-MASS MODEL

WECC	IEC	WECC 4A IEC 4B	WECC 3 IEC3A
ht	*HWTR*	5	5
hg	*Hgen*	1	1
kshaft	*kdrt*	100	100
dshaft	*cdrt*	0,5	0,5

TABLE IX. PARAMETER LIST FOR ONE-DIMENSIONAL AERODYNAMIC MODEL

WECC	IEC	WECC 3 IEC3A
Theta0	$\Theta w0$	0
Ka	*ka*	0,007

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