Value and Limitations of the Positive Sequence Generic Models of Renewable Energy Systems[1]

Abstract – This white paper gives a brief outline of the recently developed 2nd generation renewable energy system models and what they were developed for and the limitations in their applicability. As with any mathematical model of a dynamic system, there are always limitations in applicability.

1.0 Introduction

Since the influx of large levels of wind generation into the utility grid worldwide began in the early 2000's there has been a need for standard, public, flexible and openly documented models for wind generation technologies that can be used in commercial power system simulation platforms. To meet this need several organizations attempted to start such efforts in the early 2000's such as CIGRE Working Group (WG) C4.601 [1]. The early efforts did much to document clearly the dynamic performance of these technologies, but were not able to bring detailed public and standard model structures (hereafter referred to as "generic" model structures) to fruition, as at the time there was still much concern around the proprietary nature of the data and so it was difficult to acquire detailed information from a sufficiently large number of equipment vendors. In 2004, WECC commissioned a new Task Force under the Modeling and Validation Working Group (MVWG) by the name of the Wind Generation Modeling Task Force. That task force started through some communication with the CIGRE WG, but then led the way to produce the 1st generation of generic and publicly available wind turbine generator (WTG) models within WECC. Shortly after the release of the 1st generation WTG generic models, in 2010, several concerns were raised with regards to the 1st generation models. Namely, that the types 3 and 4 model catered primarily to one vendor's type of equipment (this was not a surprise since at the time of the development of the 1st generation generic models only one vendor had been forthcoming with data) and that there were some issues with the performance of the pitch controller model associated with the type 1 and 2 WTGs. At that same time NERC issued a special report highlighting the desperate need for publicly available standard (generic) models for variable generation technologies (such as wind and photovoltaics) [2], the WECC TF was renamed to the Renewable Energy Modeling Task Force (REMTF), and the International Electrotechnical Commission (IEC) started a working group (IEC TC88 WG27) charged with the charter of creating an international standard document specifying generic stability models for wind turbine generators. Thus, the WECC REMTF started anew tackling the task of creating the 2nd generation generic models, this time for renewable energy systems to include both wind and PV, and possible future technologies. Since many of the US members of the IEC group were also key members of the WECC REMTF, from early on the two groups collaborated and the core of the models for WTGs are essentially the same. Some significant differences do exist, due to the differences in European grid codes [3]. It should be noted than many of these differences were studied and presented to the WECC REMTF [4, 5], but WECC decided not to adopt them due to the added complexity without yielding added fidelity in the aspects of the dynamic performance of the WTGs that were of particular interest at the time to WECC. However, since both groups adopted a modular approach for developing the models, these differences may be accommodated in the WECC models, if desired in the future, by the addition of some alternative

[1] ***This is a brief white-paper prepared by an Adhoc group within the WECC Renewable Energy Modeling Task Force***: P. Pourbeik (lead), J. J. Sanchez-Gasca, J. Senthil, J. Weber, A. Ellis, S. Williams, S. Seman, K. Bolton, N. Miller, R. J. Nelson, K. Nayebi, K. Clark, S. Tacke and S. Lu

modules. The culmination of the 2nd generation models within WECC is reported in [6] and [7] – additional useful references are [8], [9], [10] and [11]. This brief white paper is intended to highlight the following facts:

- As explained by the brief introduction above there was a dire need for generic and public models for WTGs and other renewables.
- The efforts of the REMTF and other industry groups have been to meet this need, particularly in the WECC (and other NERC regions) where public, non-proprietary and standard models are needed for interconnection wide stability studies.
- That as with all models, regardless of the technology, there are always limitations to the models and the engineers using them must exercise engineering judgement to ensure that the models being used are adequate for the task. However, the level of accuracy in these generic models, for their intended purpose, is appropriate and consistent with established industry practice.

2.0 The Value of the Generic Model Structures

The newly developed 2nd generation wind turbine generator, photovoltaic and battery energy storage generic models (collectively hereafter referred to as the 2nd generation generic renewable energy system models) were developed in WECC with modularity in mind[2]. Ten (10) models have been developed to date (details in the references provided), which are listed in Figure 1[3]. By appropriately combining these models, as described in [10], one can build many different renewable energy systems, such as:

1. A type 1 WTG plant
2. A type 2 WTG plant
3. A type 3 WTG plant
4. A type 4 WTG plant
5. A photovoltaic (PV) power plant
6. A battery energy storage system (BESS)
7. Any combination of the above controlled by a high level over-arching plant controller[4]

The details of the models and their application can be found in the references provided. These so-called generic models are public, non-proprietary and the model structures are openly and publicly documented [6, 7, 10]. They were developed through a process of collaboration among numerous entities, including many wind turbine manufacturers, and then tested through validation simulations with actual measured field data from individual WTGs [4, 5] and PV inverters [12]. The first question that may be asked is what is the value of generic models if they are not an exact representation of specific vendor equipment? The answer is as follows

1) **Validation:** Through numerous validation cases it has been shown that the new 2nd generation renewable energy system (RES) generic models can adequately capture the dynamic time-domain

[2] The models are presently available in latest version of GE PSLF™, Siemens PTI PSS®E, PowerWorld Simulation and PowerTech Labs software platforms, and have been available in some of these tools for at least the past year.
[3] To develop the type 1 and 2 WTGs some of the older 1st generation generic WTG models are still applicable and have not been changed (see [10] for more details).
[4] As of the writing of this paper the high-level complex plant controller (*repc_b*) is still in beta version, yet to be finally approved.

behavior of various equipment over the many seconds time frame of interest in large scale stability studies. This can be achieved by appropriately parameterizing the models based on a comparison of measured to simulated response (see cases in [4] and [5]).

2) **Portability across software platforms:** The 2nd generation generic RES models have been created through a truly collaborative process with a single central specification document to ensure, as much as possible, consistency and uniformity in their implementation across the various commercial software platforms used in North America. Much time and effort were spent by many to create test cases and run these across the various platforms (and to make these tests public [13]) to ensure consistency in the results and the models across the platforms. It is certain (as with any modeling effort) that bugs may be found as we move forward, or opportunities for further improvement. Nevertheless, such an effort to ensure uniformity across the platforms was not done in the past and was a critical step since it allows for much easier transfer of data from one commercial platform to another. This is extremely important for interconnection wide studies in reliability entities (REs) such as WECC (and others in North America) since different utilities under the same RE use different commercial simulation tools and must be able to transfer data across these platforms with minimal trouble.
3) **Transparency:** For large scale power system simulations, such as WECC wide studies, standard generic models that are part of the standard library of models in commercial software tools and publicly and openly documented, are what is desired – as discussed in [2]. Such models go a long way towards avoiding problems with "black-box" coded, non-standard models typically referred to as "user-written" models, which are often vendor specific and proprietary. Even in cases where they are not proprietary there is no single reference public documentation and the models are not easily debugged. Often has been the case where an engineer is running simulations in one region of the power system, only to find some user-written model in another region causing initialization problems or other numerical issues, at which point there is no recourse but extreme frustration, since the lack of documentation leaves no room for debugging the model.
4) **Documentation:** Another issue with non-standard and user-written models developed as black-box code supplied by vendors is that some commercial tools may have a limit on the number of user-written models, and in some cases where user-written models have been developed by different vendors/suppliers they may inadvertently interact with each other since the user-written model may have common variable names (this has been experienced in some cases). In all these cases again, there is no support when such issues arise, which can be a source of much frustration for the planning engineer.
5) **Publicly Available:** In the past, and this may still be true, some vendor specific models come with a non-disclosure agreement which prevents the models from being shared and submitted to the RE. Public and generic models avoid this issue.
6) **Modeling the Future:** A final reason for the value of generic models is that they are useful for performing futuristic studies where the actual equipment to be used is not yet known, but the engineer wishes to look at the potential impact of introducing a given amount of renewable energy systems into the grid.

There are of course other reasons for using generic models, but above are the most important reasons. All of this is not to say that user-written or vendor specific models are not useful, on the contrary they are very useful and quite necessary in many cases. For example, for local studies focused on the dynamics associated with the immediate region where the plant is to be interconnected or for specialized studies such as issues related to control interactions with other nearby devices, vendor specific models may be needed. However, for the purpose of building the large scale WECC wide models, generic models should be used. Where a utility wishes to focus on a local issue, they will typically cut out the model of the local area in the WECC wide model and replace it with a far more detailed model of their local area, sometimes including vendor specific detailed models for some equipment as needed and appropriate.

Finally, it may be asked why the need to develop the 2nd generation generic models? Was the first generation not adequate? As explained in more detail in some of the references, the 1st generation generic wind turbine models had several issues: (i) they were not sufficiently flexible to capture different types of control strategies to enable them to be parameterized to represent different vendor equipment (see for example, Figure 2), (ii) in some cases important aspects of the dynamics of the equipment were not represented (e.g. the pitch controller for the type 1 and 2 WTGs, see [6] and [10]), and (iii) the models were not completely standard across the various commercial tools (see appendix of [10]).

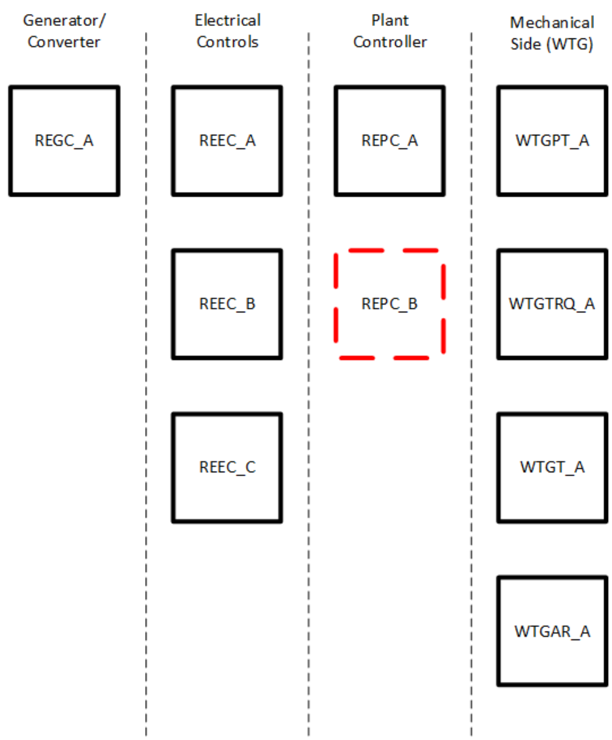
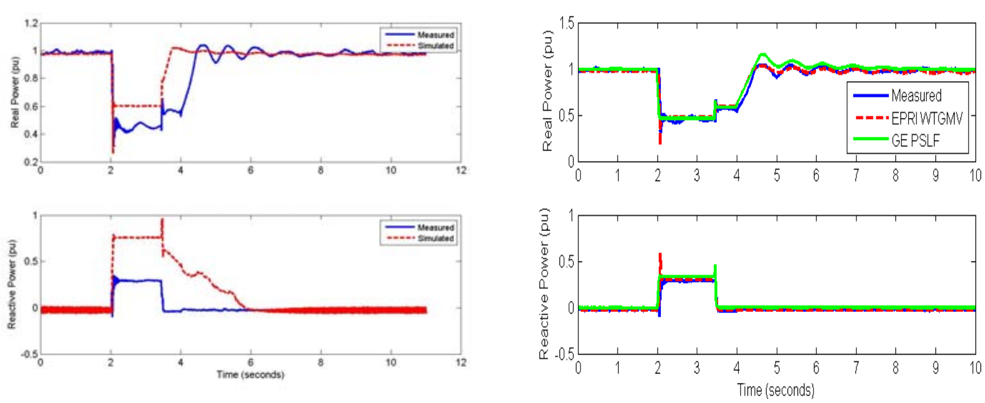


Figure 1: The list of ten (10) models that comprise the 2nd generation renewable energy system models.



a) 1st generation generic WTG model b) 2nd generation generic WTG model

Figure 2: A comparision between measurement (blue) and simulation (red and green) for a type 3 WTG. Both cases are the same equipment and event. In a) the comparision is between measurement (blue) and simulation(red) using the 1st generation generic WTG type 3 model, and in b) the comparision is between measurement (blue) and simulation (red – EPRI tool and green – GE PSLF™) using the 2nd generation generic WTG type 3 model. The results are for a single WTG.

3.0 The Limitations of the Generic RES Models

By the very definition of the word model, all models are simply an attempt at emulating the behavior of an actual physical system and therefore limited in their domain of applicability and accuracy. The generic RES models are no exception to this rule. These models were developed with many underlying assumptions, in order to facilitate the ability to make them generic and flexible enough to cover a sufficiently wide range of possible control strategies and thus various vendor equipment. These assumptions are:

- They were developed with a focus on usage in commercially available positive sequence stability software programs, which are predominantly used in planning studies by utilities in North America.
- To consider dynamics in the typical range of stability studies (0.1 – 3 Hz)[5], remembering that all other models are only truly good within this range of frequencies in large scale stability models. The control loops within the models (e.g. closed-loop voltage control) may also consider frequencies ranging up to 10 Hz.
- Given the above assumption, for type 3 WTGs, the stator flux dynamics are neglected.
- All converter high-frequency controls are modeled as algebraic equations, since these controls are typically running in the kilo-hertz range and thus several orders of magnitude outside the range of frequencies of concern in stability analysis.
- The converter phase-lock loop (PLL)[6] has been neglected for the most part. The low voltage active current management logic attempts in a rather rudimentary way to approximate the response of the PLL during severe voltage dips.
- In using the generic models it is assumed that wind speed (and solar irradiation) is constant during a stability simulation[7] (10 to 20 seconds) – this is of course not true in real life, but a necessary simplification for planning analysis since particularly when performing stability runs for future planning cases, there is no way to know the exact or worst case wind (solar irradiation) variability in the seconds time-frame[8].

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[5] For a detailed discussion of why power system stability studies are confined to these ranges, the reader should consult a book such as P. Kundur, *Power System Stability and Control*, McGraw Hill, 1994.

[6] A phase-lock loop (PLL) is a control system that generates an output signal that is in-synchronism (locked in phase) with its input signal. In the case of inverter based generation, the PLL keeps the inverter in synchronism with the network frequency.

[7] The assumption that wind speed is constant is also driven by the simplified aero-dynamic models used in these generic WTG models. This, and many other reasons, also mean that these models at not appropriate for long-term simulations.

[8] Studies have been conducted that look at the effect of large and fast expected second to second variations in wind or solar irradiation on system dynamics. However, in these cases significant simulation work is required from experts other than power system engineers (i.e. expert consultants in modeling the wind or solar resource) who can thus develop the expected wind or irradiation patterns and how these will translate into second by second (or minute by

- Emulated inertial response capability of type 3 & 4 WTGs are not modeled. However, primary frequency response capability of type 3 & 4 WTGs is modeled.
- All models are "emulations" of functional features of most typical control strategies – not an exact duplication of any original equipment manufacturer (OEM) equipment.
- These models were developed for use in the dominant positive sequence simulation platforms used in North America. Therefore, by their very nature, these models cannot be used for accurate assessment of unbalanced conditions.
- Since the models do not incorporate the inner current control-loops of the converter, the PLL and various other detailed aspects of the converter, they are not really suited for studying the interconnection details of a wind power plant (or solar PV plant) to a weak system (i.e. short-circuit ratio[9] at the point of interconnection being relatively low, e.g. less than approximately 2 or 3). In these cases the detailed design and interconnection studies may need to be done with vendor specific stability models in positive sequence programs, with vendor specific 3-phase models (e.g. in PSCAD, EMTP-RV etc.) being used, when necessary, to augment and help guide the stability analysis in the positive sequence program. Thereafter, for the purposes of providing a model for use in the WECC wide stability case, the generic models may be used, with the expressed understanding that they are not intended for localized detailed studies, but rather for the purposes of meeting the needs of WECC to have a standard model in the interconnection wide system model.
- The models cannot be used for detailed studies that relate to phenomena such as potential torsional interactions between the wind turbine generator and the electrical power system (e.g. nearby series capacitor). Such studies require detailed vendor specific models which can accurately capture higher frequency phenomena (i.e. 3-phase PSCAD, EMTP-RV, etc. models).
- The generic models are not necessarily appropriate for studying wind-turbine start-up.
- As explained in more detail in other documents (e.g. [5]), it should be noted that these positive-sequence generic dynamic models for inverter-based generators tend to produce a short-duration (a cycle or so) voltage spike at fault clearing. These spikes should be ignored in most cases, as they do not represent the performance of actual hardware. In reality such momentary spikes are far smaller in magnitude and duration for the actual equipment due to the very fast converter controls. They are simply a consequence of the model's limited bandwidth, integration time step, and the way the current injection models interface with the network solution in positive sequence programs.

Also, it should be noted that the generic models were developed keeping in mind the need for good numerical behavior, with a reasonable integration time step. Also, as with all power system models there is a compromise between accuracy and detail, for inordinate accuracy demands for any individual power system component leads to excessive complexity and does not necessarily lead to better planning decisions. The level of accuracy in these models, for their intended purpose, is appropriate and consistent with established industry practice.

minute) variations in wind or PV plant output over time. This data can then be used and played into the power system model.

[9] By short-circuit ratio is meant the ratio of the short-circuit MVA available at the particular node in the network to the total MVA rating of the equipment/power plant in question.

4.0 Summary and Conclusions

A brief overview has been given in this white-paper outlining the intended purpose and value of the recently developed 2nd generation renewable energy system models. In addition, we have summarized their limitations, which primarily fall into the following categories:

1. They are not intended for use in performing studies of phenomena outside of the typical range of frequencies of interest in power system stability studies (i.e. 0.1 to 3 Hz). Therefore, these models are not adequate for studying phenomena such as switching transients, torsional interactions, harmonics, etc.
2. They are not intended for detailed analysis of unbalanced phenomena.
3. They are not intended for detailed local studies associated with control tuning and design for the interconnection of wind/PV plants to very weak systems (i.e. short-circuit ratios below approximately 2 or 3).

Further research and development is continuing by many of the stakeholders to look at means of either improving the models or the simulation methods (e.g. integration algorithms) to perhaps both extend and better define the boundaries of the application of these positive sequence generic models. In the end, as with any model (no matter how detailed) engineering judgment and the advice of experts (e.g. equipment vendor, experienced consultants/researchers etc.) should be sought when applying the models.

5.0 References

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