Experiences with Wind and Solar Plant Modeling and Validation for Interconnection Studies

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***Abstract*—The increasing numbers and penetration of wind and solar plants requires good power system models in order to accurately perform transmission planning and generator interconnection studies. However, these resources are inverter based and this characteristic challenge traditional modeling approaches. The Western Electricity Coordinating Council Renewable Energy Modeling Task Force (WECC REMTF) has taken an industry lead role in developing generic positive sequence models. These models have become a requirement for most projects, allowing the transmission operator to perform power system transient stability analysis. In this paper, we will discuss typical experiences in developing and validating steady state and second-generation generic wind and solar plant dynamic models to fulfill the North American Electric Reliability Corporation (NERC) Modeling, Data, and Analysis (MOD) requirements. The validity of these positive sequence models with the corresponding ElectroMagnetic Transient (EMT) detailed models of these plants is also considered as an additional requirement by some Independent Systems Operators (ISOs) during the generation interconnection application. Actual experiences in performing such validation will also be presented along with conclusions and recommendations from this practice.**

***Index Terms*—wind and solar power plants, WECC generic models, EMT plant models, NERC MOD Requirements, model validation and testing**

I. INTRODUCTION

Variable generation such as wind and solar plants utilize inverter-based technology with state-of-the-art control algorithms for active/reactive power, voltage and frequency controls to interface with the grid. Therefore, it is very important that computer simulation models of these plants are as accurate as possible for large scale interconnection studies. Only the accurate models can represent the actual steady state and dynamic characteristics of the plant as they operate in the field.

In the past, the original practices were to utilize vendor specific detailed models of the wind and solar plants. However, these vendor specific models turned out to be hard to utilize throughout the industry due to their incompatibility with the grid planning processes of the regional reliability organizations. At the same time, such models are hard to maintain as they are proprietary and are difficult to be adapted with the changing software versions over the time. Therefore, in order to standardize this model development efforts, Western Electricity Coordinating Council Renewable Energy Modeling Task Force (WECC REMTF) developed the generic positive sequence models and so, the power systems software vendors - Siemens PTI, General Electric (GE), and PowerWorld have implemented the generic structure into their modeling platforms. Therefore, in the recent years, the dominant practice is to utilize these WECC generic models for system planning and interconnection studies. Now, transmission system operators (TSOs) do not usually accept vendor specific, user defined models with the generation interconnection application [1]. Submitted models must be in a Phase II or 2nd generation WECC generic model format to be compatible with the given version of positive sequence power system studies software platforms such as Siemens PTI PSS/e or GE PSLF.

The most important aspect of such generic model development process is evaluated for the generation plant response for large system disturbances. Another important aspect is that the plant protection characteristics must be included. The plant frequency and voltage response capabilities should also be included and validated. Now that the industry is generally favoring WECC generic structure models, benchmarking is needed to validate the response by considering the responses from the vendor-specific models, using more granular EMT models of the same plant, or using Phasor Measurement Unit (PMU) measurement of the disturbance events. The validation of the models by utilizing the actual measured events from the field is considered extremely important and the industry is heading towards this direction in calibrating the models [2]. We have been involved in different types of model validation efforts depending on the availability of the model benchmarking responses. This paper presents some of our experiences in this area of plant modeling and validation and recommends for some changes in the industry to make this process better.

The rest of the paper is organized as follows: Section II will briefly describe the development of wind and solar plant aggregated power flow model, Section III describes WECC second generation generic dynamic models utilized to model wind and solar plants; Section IV discusses some of the applicable NERC MOD requirements; Section V presents several examples of our modeling and validation efforts and experiences; and Section VI concludes the paper with some of the takeaways from our modeling experiences.

II. Wind and Solar Plant Power Flow Model

In order to perform bulk power systems dynamic studies including large utility scale wind and solar plants, the equivalent of the plant collection system is created together with the equivalent aggregated pad-mount transformer and aggregated wind or solar plant model represented by the positive sequence impedance characteristics. For example, large utility scale solar or wind farm with 4 feeders represented by A in Figure 1 is required to be reduced and represented by a single machine equivalent system model as given by B in the same figure.

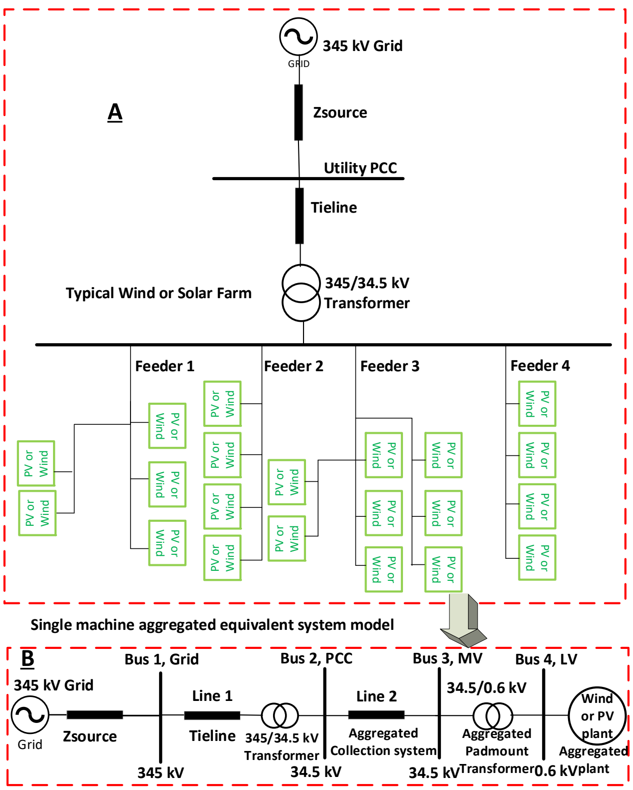

Figure 1. Typical utility scale wind or solar farm represented by a single machine equivalent representation.

The methodology of representing groups of several wind turbines of same types by creating an equivalent of the collection system is described in [3]. The methodology to create an equivalent for the collection system and the wind farm with different types of wind turbine generators is described in [4]. The equivalent transformer MVA rating representation for the entire wind power plant can be computed as the rating of a single transformer multiplied by the number of turbines in the plant:

$$MVA_{NXFMR_{WF}} = MVA_{NXFMR_{WTG}} \bullet N_{Turbines}$$

The transformer impedance will be calculated on this new aggregated transformer base for the entire farm. Similarly, the total MVA rating of the entire wind farm is given by:

$$MVA_{WindFarm} = MVA_{WTG} * N_{Turbines}$$

Similar aggregation methodology is applied to the solar plants.

III. WECC Second Generation Generic dynamic Models

Most wind plants utilize Type 3 (doubly fed induction generator) and Type 4 (full converter type) wind turbines. Solar plants utilize inverters where many aspects are like the Type 4 wind turbines. The converters of these plants are used to control active and reactive power independently. Nowadays these generators satisfy the Low Voltage Ride Through (LVRT) requirements utilizing converter control characteristics, without requirement for external reactive support. The dynamic response of these types of turbines during grid disturbances are entirely defined by the current limited converter controls characteristics.

Table 1 WECC Generic Models Type 3/4 Wind Turbine Generators.

PSS/e Model Name	PSLF Model Name	Description
REGCAU1	Regc_a	Renewable Energy Generator/Converter Model for Type 3/4 wind machines
REECAU1	Reec_a	Generic Renewable Electrical Control Model for Type 3/4 wind machines
WTTQAU1	Wtgq_a	Generic Torque Controller for Type 3 Wind Machines
WTDTAU1	Wtgt_a	Generic Drive Train Model for Type 3/4 Wind Machines
WTARAU1	Wtga_a	Generic Aerodynamic Model for Type 3 Wind Machine
WTPTAU1	Wtgp_a	Generic Pitch Control Model for Type 3 Wind Generator
REPCAU1	Repc_a	Generic Renewable Plant Control Model for Type 3/4 wind machines

Type 3 turbines have some unique characteristics, for example, they will utilize the pitch control in some dynamic modes of operation. Table 1 shows the WECC Phase II generic models utilized to model a wind farm with Type 3 wind turbines in PSS/e and PSLF software platforms. The converter model, REGCAU1, electrical control model, REECAU1, and drive train model, WTDTAU1 are used to model Type 4 wind turbines together with the power plant controller model. The solar plants are modeled considering the generator/converter model, REGCAU1, electrical control model, REECAU1 and plant controller model, REPCAU1. The details on the second generation WECC generic models can be found in references [5], [6], [7], [8], [9], and [10].

IV. NERC MOD REQUIREMENTS

With regards to utility scale wind and solar plants load flow and dynamic modeling, North Electric Reliability Corporation (NERC) started development of model verification standards, MOD requirements in the year 2007. NERC approved MOD-025, MOD-026, and MOD-027 in the year 2013. MOD-025 provides the requirements for active and reactive power capabilities verification, MOD-026 provides the requirements for generation and excitation control model or plant volt/var control functions verification, and MOD-027 covers generator turbine control model or active power/frequency control functions verification. The requirements of each of these MOD standards are described in [11].

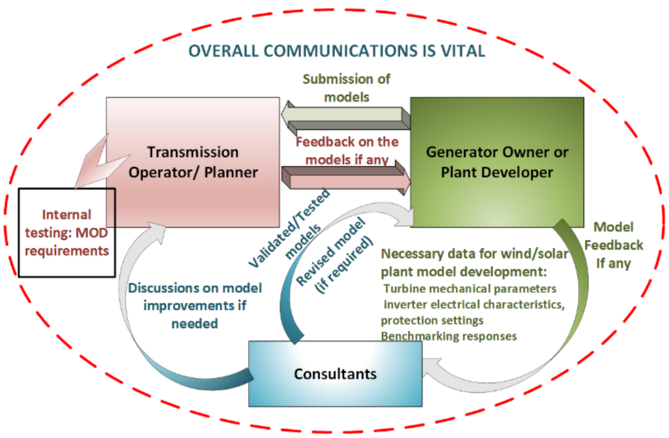

Figure 2. Overall process of wind/solar WECC 2nd generation generic model development and validation.

Figure 2 shows the process involved in finalizing the WECC generic 2nd generation models that are ultimately utilized for the bulk power systems studies. Generator plant owners and developers often utilize consultants for the model development and validation task. They provide all the necessary manufacturer's data such as turbine mechanical parameters, inverter electrical characteristics, active and reactive capability, voltage ride through settings and controller parameters as available. They are also responsible for providing any necessary benchmarking responses of the plant. Their consultants utilize the provided data and perform an intellectual tuning of the model parameters in the generic model structure to match the provided plant responses. Once the model is developed and tested for different disturbance conditions, consultants submit the models to the generator owner. The generator owner submits the model to the transmission operator for their internal testing to see if it satisfies the necessary MOD 26/27 requirements. If it does not satisfy any one of the requirements, the generator owner and then the consultants are notified of the problem and are requested to modify and submit the model again. This iterative process persists until the submitted model is finally approved by the transmission system operator. The continuous communication between the generator owner, transmission operator and the involved consultants is very important in order to finalize the model approval process following successive model validation steps.

V. VARIABLE GENERATION MODELING AND VALIDATION EFFORTS

Typical model development includes either a single wind turbine model utilizing WECC 2nd generation model structure or together with the plant characteristics. NERC MOD requires the aggregated load flow model as shown in Figure 1 and the aggregated plant dynamic model in either Siemens PTI PSS/e or General Electric PSLF software programs to be delivered to the transmission operators.

The model development requires a detailed knowledge of the generic model structure that uses different voltage and power control loops. The controller time constants, gains, voltage, reactive power and frequency dead bands and droop characteristics should be modeled accurately to mimic the practical response of the plant in the field.

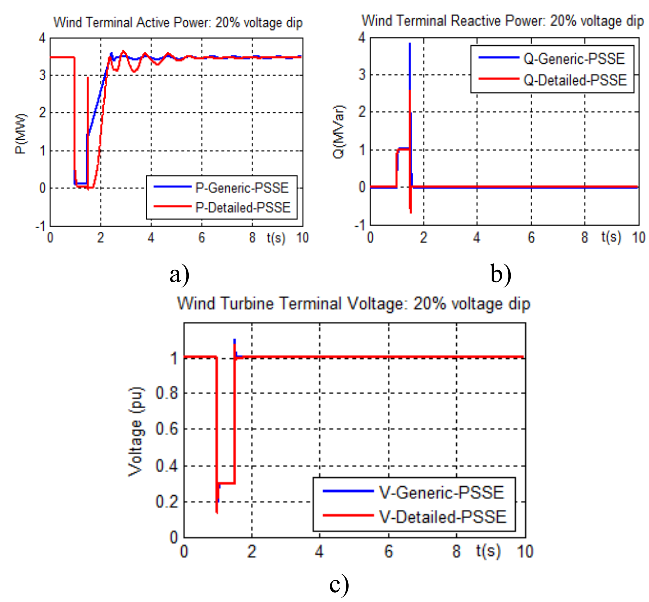

Figure 3. Validation of generic 3.5 MW Type 3 WTG model in PSS/e considering the vendor specific (detailed) model of the same turbine.

The validation of these model is not always an easy task. It relies on the availability of the benchmarking responses. The benchmarking of an individual machine or the entire plant could either come from the monitored event record from the field installed PMUs, from the detailed or vendor specific model of the same plant, from generic model in a different software platform, or even from the more precise Electromagnetic Transient (EMT) models.

Figure 3 shows a) active power, b) reactive power, and c) voltage at the terminals of a 3.5 MW Type 3 Wind Turbine

Generator (WTG) obtained from the generic PSS/e model as compared to the vendor specific detailed PSS/e model. The event tested was a slightly remote fault that caused around 20% voltage dip at the WTG terminals. The response characteristics of these quantities for this disturbance condition matched closely between these two different types of models.

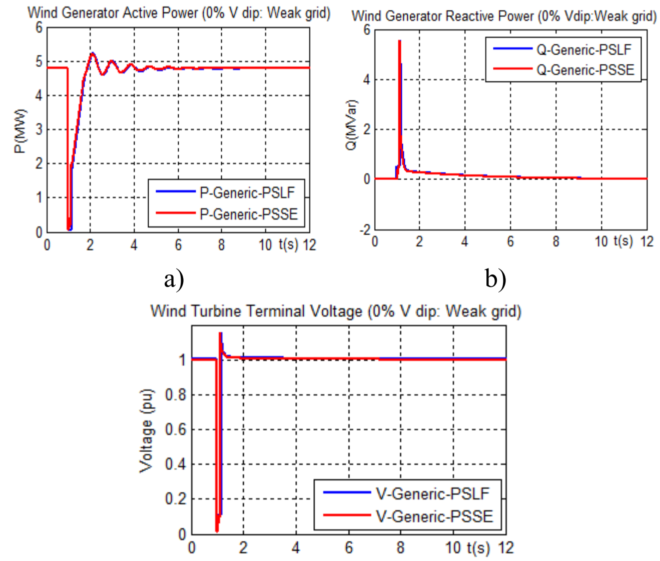

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Figure 4. Validation of generic 4.8 MW Type 3 wind turbine generator model in PSLF utilizing the model responses of the same turbine in PSS/e.

Figure 4 shows active and reactive power and voltage responses of a 4.8 MW Type 3 WTG. In this case, the response of a WTG model developed in the GE PSLF platform was validated against the generic model responses from PTI PSS/e generic model responses. The disturbance considered in this case is a three-phase fault very close to the WTG terminals so that the voltage during fault is close to 0 per unit. The dynamic responses of these two models during and after the disturbance match very closely.

Figure 5 shows the validation results of a 2 MW WTG in PSS/e platform by using the PMU data from the field that was provided for 13% of the total turbine generation. The event that was recorded by PMU in this case was for some remote fault condition that caused around 90% and 85% voltage dips in two successive events.

The developed model could replicate the PMU data to some degree of accuracy. However, as the generation level of the WTG was at a low output, it was hard to consider just this particular measurement for model validation. In order to validate this model further, we also performed other tests for the faults in the close proximity of the wind turbine to verify the model responses after fault for such low voltage dip conditions.

Obtaining the PMU measurements of the disturbance events from the field to validate the simulation models has always been the most challenging task in our experience. Smaller generation operators mention that they do not have PMUs installed at the farm. In some cases, the plants have installed PMUs, but there are no event data available.

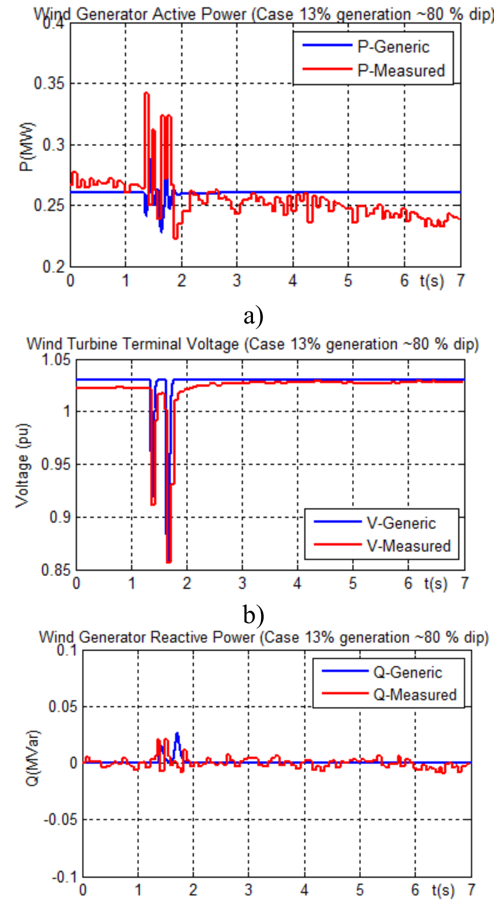

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Figure 5. Turbine model validation with the PMU data for 13% generation from a single 2 MW wind turbine in a 200 MW plant.

In addition to the separately validated PSS/e or PSLF generic models of the wind and solar plants, some TSOs are now requiring the benchmarking of the generic model developed in either PSS/e or PSLF platform with the corresponding EMT type models of the plants. The EMT models of the plants are mainly developed and are available in PSCAD software platform.

Figure 6 shows the benchmarking results of PSCAD model of a 20 MW solar plant as compared to the PSS/e model of the same plant for a three-phase fault causing 0% voltage dip at 34.5 kV Point of Common Coupling (PCC) of the plant. The active power, reactive power and voltage at the solar PV terminal as well as PCC show a good match between these two models. Despite the modeling differences between PSCAD and PSS/e software platforms, the plant models could be validated once against the another. This provides more confidence of the validity of the PSS/e generic model for bulk power systems studies.

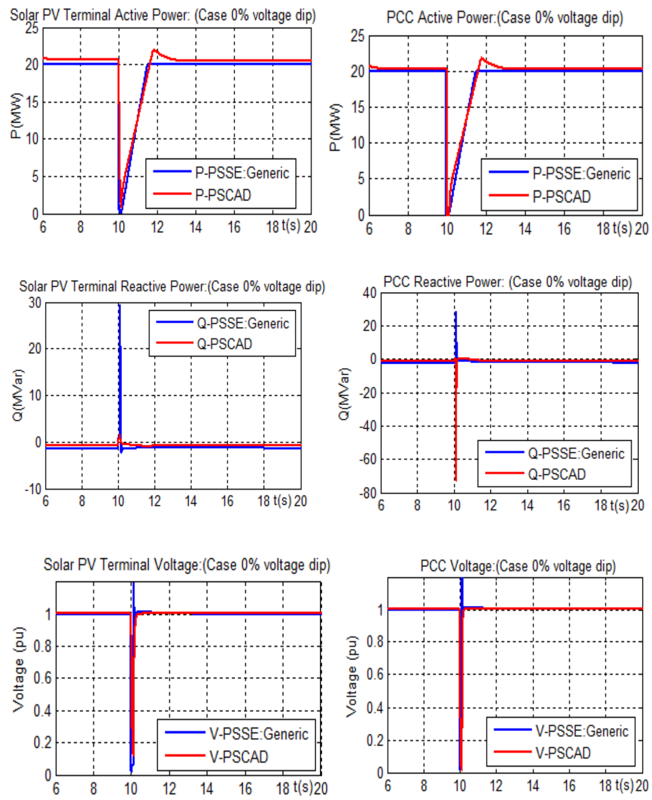

Figure 6. PSCAD Vs PSSe generic model benchmarking results for a 20 MW solar plant.

Through several other series of testing and validation of wind and solar plant models in strong and weak grid conditions, experience has shown that it is difficult to find the common controller gain parameters in generic structure that works well with both strong and weak grid conditions. The parameters of the voltage and reactive power control loops in the generic models need to be adjusted when the grid becomes weak with the Short Circuit Ratio (SCR) less than 5. This problem can be addressed by making the gain parameters adaptive by calculating the parameters as a function of the grid strength.

VI. CONCLUSIONS AND RECOMMENDATIONS

In this paper, we have discussed our experiences with wind and solar plant modeling and validation for bulk systems studies by presenting several of our model development and validation examples. The best way of validating such utility scale plant models is to utilize the measured event data from the field. PMUs can capture highly precise event recordings and therefore, is the best data source for model validation. However, the pressing need of the industry is the availability of such event data during the model development and testing phase. The generator and plant operators and developers should make sure such data are available and are provided to the entity involved in model development on time. Also, in order to fulfill the mentioned NERC requirements, there should be a close loop communication between generator operators or developers, transmission operators and the consultants who are involved in the model development, testing and validation. The performance of WECC generic models can be improved to work equally well in the strong and weak grid conditions. The adaptive adjustments of the controller gain parameters based on the system short circuit strength can be considered for the possible model improvements.

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