Experience in Certification according to the Indian Wind Turbine and German Grid Connection Certification Scheme

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***Abstract*— The aim of this paper is to exploit the long experience of UL (DEWI-OCC) in the field of grid connection certification according the German Grid Codes in order to propose a relevant Certification Scheme for India considering the latest developments in the Indian Regulations released by the Central Electricity Authority of India (CEA) in February 2019 [12]. The proposed scheme will also consider the latest progress within the working committees of the FGW and IECRE, where UL is an active member. This committees develop and issues the Technical Guidelines for Certification, Testing and Modelling/Simulation to ensure the high quality of the certification process of decentralized power generation.**

Keywords-component; Central Electricity Authority (CEA); certification, assessment, grid code compliance; harmonics, simulation, model validation, IEC, IEEE; FRT, HVRT, LVRT.

I. INTRODUCTION

UL's certification services support grid integration for decentralized power generating units and power plants according different international Grid Codes like the Central Electricity Authority (CEA) 2019 [12], CEA 2013 [11], CEA 2007 [10], German Grid Code (BDEW) [1], VDE-AR-N 4110 medium voltage [2], VDE-AR-N 4120 high voltage [3], VDE-AR-N 4130 extra high voltage [4], FGW technical guideline 8 (TG8, certification procedure) [9], technical guideline 4 (TG4, simulation and modelling requirements) [8] in connection with technical guideline 3 (TG3, testing procedure) [7], IEC 61400-21 [5], IEC 61000 series [14], [15], [16], [17] and IEEE519 [13] , etc. Basis of the certification services is the accreditation of DIN/IEC/ISO 17065 [19] by the German Accreditation Body (DAkkS). A dedicated working group (REMC WG 010) [20] has also been created by IECRE Management Committee (REMC) for developing an operational document (OD) for grid code compliance certification referencing to internationally accepted IEC standards. This OD will be used internationally for grid compliance certification. UL is an active member of this REMC WG 010 [20].

Grid compliance is a relatively young topic in the field of conformity assessment and at present there are only a few countries that have a dedicated procedure or guideline (grid codes) providing the requirements for a grid compliance certification. In the last years, these grid codes have undergone substantial development and new requirements have been introduced for the grid connection requirements of power generating units (PGU) and power generating systems (PGS). The initial versions of the grid codes were mostly concerned with harmonics, flicker and Low Voltage Ride Through Capability (LVRT). But recent developments in the international grid codes have introduced more sophisticated control requirements like active and reactive power control functions for grid support during normal operation or Fault Ride Through (FRT) events, frequency control with respect to voltage or active power, etc. Not all grid codes have the same complexity of requirements however the grid codes that are available today are broadly categorized under four major areas:

i. Power Quality requirements

ii. Control requirements

iii. Testing requirements

iv. Model validation

v. Site specific requirements

Recent efforts are being made for harmonization of the requirements for grid connection internationally, in order to facilitate the Original Equipment Manufacturers (OEMs) to design and fulfil their PGUs for most grid codes, as well as make the integration process of Renewable Energy Sources (RES) into the grid faster and more efficient for the regulatory bodies and grid operators.

In India, the Central Electricity Authority (CEA), has published an amended Regulation in February 2019 [12], with modifications of the requirements from the previous regulations from 2007 [10] and 2013 [10]. The new regulations include further control requirements like Overvoltage Ride Through Capability (HVRT), frequency control etc. UL gained experience with certification of certain international grid codes which encompass these requirements with more stricter evaluation criteria as compared to the ones required by CEA 2019 [12]. UL wishes to use this experience in order to propose innovative solutions for certification according to CEA 2019 [12] in order to facilitate a faster conformity assessment with more efficient utilization of resources and available evaluation works in other international grid codes. The proposal will include specific suggestions and recommendations for processes, for example on how the test results from a different PGU model can be evaluated to verify if parts of the existing test and evaluation is technically comparable to the PGU under certification or not, how to transfer test results to other PGU variants, how to use software simulations to verify certain control requirements of the CEA 2019 [12], etc. UL's proposed procedure will be based mostly on the transfer rules out of the IEC 61400 series and the FGW TG8 [9] . The use of these rules ensure a transfer which is technically feasible and internationally recognized and ensures sufficient accuracy of the transferred results.

In addition, the requirements for conformity assessment according to CEA 2019 [12] will be discussed in detail and proposals for the improvement and optimization of this procedure will be presented, based on the extensive experience of UL.

Regarding the structure of the paper, in Section II, the summarized requirements for grid compliance, generalized for international grid codes is presented. In Section III, the amended requirements of the CEA standard for grid connectivity are presented. Section IV includes proposals for transfer of test results of power quality or electrical characteristics like flicker, harmonics, etc. between different grid codes or different PGU models based on technical similarity and use of software simulations for verification of control requirements like Fault Ride Through (FRT), active and reactive power control, frequency control. The conclusions of the present work are summarized in Section V.

II. GENERALISED GRID COMPLIANCE REQUIREMENTS

As mentioned in the previous section I, in general the grid codes that are available today are broadly categorized under four major areas:

i. Power Quality requirements

ii. Control requirements

iii. Testing requirements

iv. Model validation

v. Site specific requirements

Among the power quality requirements topics like electrical characteristics of the PGU are verified. These can be harmonic or flicker emission (during continuous operation or switching events), DC current injection, maximum active and reactive power capability (at steady or transient time instances). These are verified based on measurement results.

Among the control requirements, the dynamic performance of the PGU as a response to transient events are verified. These can be FRT capability verification, active and reactive power control during FRT events, frequency response with respect to active power or voltage. These can be verified based on measurement results or software simulations performed on a software model of the PGU, that has been previously verified based on measurement results.

The testing requirements are based on the required control requirements. The testing of the power quality, active and reactive power capability, FRT functions etc. has to be done by an accredited test lab according DIN/IEC/ISO 17025 to ensure the quality of the test results which are the basis of the further assessment. The testing has to be done on the specific PGU type.

Software model validation is a specific requirement according to the FGW guideline TG4 [8]. For the control requirements like FRT are initially measured on a real test grid. The test results are then matched with the performance of the software model under simulation with the exact test conditions. This model can be used for further studies like FRT simulations in a modelled PGS, in case additional control requirements are added or the parameters of the connected grid are substantially different from the test grid.

The site specific requirements can be verifying local requirements, or fulfillment of the communication procedure of the PGU with the local load dispatch center (LDC), or fulfilment of the requirements of the connecting substation, etc. These can be verified only site specific and cannot be covered under the scope of a grid compliance conformity statement issued for a specific PGU type.

The conformity assessment for the grid compliance is very extensive according to the German Grid Code (BDEW) [1], VDE-AR-N 4110 medium voltage [2], VDE-AR-N 4120 high voltage [3], VDE-AR-N 4130 extra high voltage [4], FGW technical guideline 8 (TG8) [9]. This is categorized in three parts as presented below as an example.

1. Unit Certification

i. Testing and evaluation of the power quality (harmonics, flicker) and control (active and reactive power capability and functions, LVRT, HVRT, etc.)

ii. Evaluation of the design, control and functions of the PGU

iii. Validation of simulation model based on FRT results

iv. Issuing unit certificate for a specific PGU type

2. Systems Certificate

i. Evaluation of the design (cable laying, transformer, etc.), control, protection, functions of the PGS comprising of multiple PGUs with existing unit certificates

ii. Modelling and simulation of the PGS to analyze the FRT capability and other control requirements of the entire PGS at the grid connection point

iii. Issuing of systems certificate for the specific PGS before commissioning of the first PGU

3. Conformity declaration

i. Evaluation of the commissioning, protection test, parameterization and As-built protocols

ii. Inspection of erected PGU

iii. Inspection of Grid Connection Point like substation/transformer or transfer station in case of protection, communication, parameter and control system

iv. Issuing of conformity declaration based on the PGS certificate

III. CEA REQUIREMENTS FOR GRID COMPLIANCE

A summary of the complete scope of CEA requirements [10], [11], [12] in power quality, control capability and response in transient events is given below.

A. Electrical characteristics in normal operation (Power Quality requirements)

The CEA notification [11] does not refer explicitly to any measurement guideline (method) but only on the acceptance criteria (limits):

i. Harmonic current emissions should be within the limits specified in the standard IEEE 519 [13]

ii. DC current injection of the PGUs at the point of connection should not be greater than 0.5% of the rated current I_n

iii. Flicker emissions should be within the limits specified in the IEC 61000. Since IEC 61000 is published as parts dealing with different topics UL interprets the requirements of flicker should observe the IEC/TR 61000-3-7 [14]

The above requirements have remained unchanged in the new CEA amendment [12].

B. Control requirements

The following requirements apply:

i. *Reactive power capability:* PGUs shall be capable of supplying the necessary reactive power in order to ensure that power factor is kept within the limits of 0.95 lagging and 0.95 leading

ii. *Frequency range test:* PGUs shall be capable of remaining connected to the network and operate within the frequency range of 47.5 Hz to 52 Hz. In addition, they should be able to deliver rated power in the frequency range of 49.5 to 50.5 Hz, subject to availability of the primary energy source (i.e. wind speed or solar radiation). This performance shall be also achieved with a voltage variation of up to ± 5 %.

iii. *Undervoltage ride-though (LVRT) capability:* The required voltage profile is shown in TABLE I. and Fig. 1. The requirements for grid support during the voltage dips are the following:

- During the voltage dip, the supply of reactive power has first priority, while the supply of active power has second priority.
- Active power after voltage dips clearance shall be restored to at least 90% of the pre-fault level within 1 sec of restoration of voltage.

iv. *Overvoltage ride-though (HVRT) capability:* Fault-ride-through (FRT) capability in the amended CEA Regulation [12], includes also the requirement for HVRT Capability of PGUs. The required voltage profile is shown in TABLE I. and Fig. 1. For overvoltage events, the only requirement is that the PGUs shall remain connected to the grid

v. *Active power set-point control:* PGUs shall have the capability of set-point control of the active power following the orders given the relevant LDC.

vi. *Active power ramp rate limitation:* PGUs shall be equipped with the facility for controlling the rate of change of power output at a rate not more than ± 10% per minute.

vii. *Frequency sensitive mode:* PGUs shall have the capability to control active power in case of over – and under-frequency at a droop between 3 to 6% and a dead band ≤ 0.03 Hz.

viii. *Synthetic inertia:* For frequency deviations < 0.3 Hz, the station shall have the facility to provide within 1 second power frequency response of at least 10% of the maximum active power capacity.

It should be noted that, according to CEA, requirements from (v) to (viii) apply for generating stations with installed capacity of more than 10 MW connected at voltage level of ≥33 kV.

C. Grid protection system

According to CEA initial Technical Standard [10] the protection system shall reliably detect faults on various abnormal conditions.

TABLE I. MINIMUM REQUIREMENTS OF LVRT/HVRT CAPABILITY OF PGUS ACCORDING TO CEA REQUIREMENTS

Percentage undervoltage at the interconnection point V_T/V_n[a]	Fault duration [ms]
0.15	300
0.85	3000
0.90	10000
$0.90 \le V \le 1.10$	Continuous
$1.10 < V \le 1.20$	2000
$1.20 < V \le 1.30$	200
> 1.30	0 (Instantaneous trip)

a. V_T/V_n is the ratio of the actual voltage to the nominal system voltage.

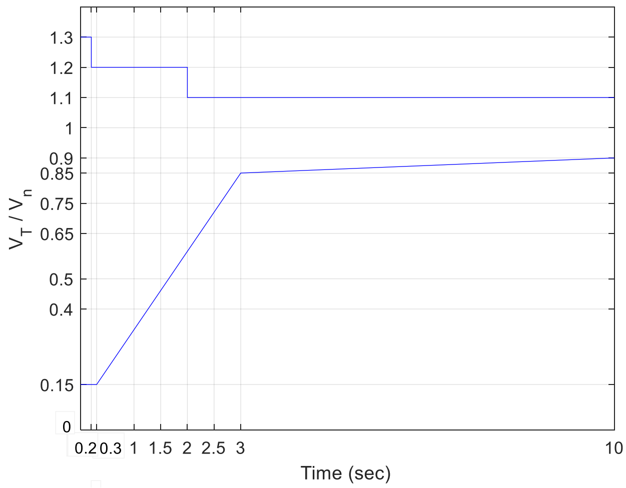

Fig. 1. Lower and upper limit of the voltage-against-time profile of any or all phases at the interconnection point according to the amended CEA Grid Connectivity Standard [12].

IV. Proposal for Certification Procedure Based on Existing Test Reports and Software Simulations

A. *Harmonics and flicker measurements*

CEA [10] requires that the harmonic current injection of PGUs shall not exceed the limits specified in standard IEEE 519 [13]. The flicker emissions of PGUs should comply with the limits imposed in IEC 61000 series of standards, which in turn corresponds to IEC/TR 61000-3-7 [14]. These requirements remained also unchanged in the latest CEA Regulation [12].

But CEA only informs about the limits, but does not clarify measurement procedure. From UL's experience with international standards we propose that the harmonics measurement procedure to be followed with either IEC 61400-21[5] or IEC 61400-21-1 [6]. Since these are internationally recognized standards most OEMs have already measurement reports for their PGUs according to these standards, therefore the results can be transferred much faster with efficient use of resources, without the need for new measurements. A basic difference between this new IEC standard, compared to the old IEC 61400-21 [5], is the harmonic aggregation method, which is now common with the IEEE 519 method. However, there are still differences, which have to be taken into account when assessing the relevant grid compatibility. The basic differences between the two guidelines are presented in TABLE II. In the same table, the contents of the old IEC 61400-21 are also included to highlight the changes in the procedure followed up to now. For flicker measurements, the test procedure of IEC 61400-21-1 is sufficient, as it illustrated the behavior of the tested unit over the complete active power range. The flicker report shall be based on 10-min flicker measurements in continuous operation of a duration, which is long enough so that sufficient data in all 10% power bins from 0% to 100% of the nominal power are collected. In addition to flicker in continuous operation, the relevant flicker produced during switching operations shall be calculated as well as the relevant voltage change. The measurement reports, typically do not include any assessment of compliance with the limits included in the IEC 61000-3-7 [14].

Regarding transfer of measurement results between two PGUs, technical similarity needs to be investigated at first and as a second step the parameters that effect harmonics needs to be identified. This can be complex and depends highly on the scenario and type of PGU, however to make the proposal clear two examples with most popular type of PGUs, wind turbine (WTG) and photovoltaic (PV) is presented in TABLE III. Mainly the transfer rules are leaned on the requirements of the FGW technical guideline 8 (TG8) and IEC61400-22.

TABLE II. Comparison between IEC and IEEE standards with regard to the harmonic evaluation procedure

Parameter / procedure	IEC 61400-21, Ed.2	IEC 61400-21-1, Ed.1	IEEE 519
Instrumentation	Compatible with IEC 61000-4-7 and 61000-4-30		
Averaging time	10 min	10 min	3s / 10 min
Number of measurements	≥ 3 for each 10 % power bin	≥ 7 for each 10 % power bin	≥ 24h for 3s and ≥ 7days for 10 min
Aggregation method	Arithmetic	Arithmetic	Geometric
Harmonic frequencies	up to 9 kHz	Up to 9 kHz	Integer harmonics up to 50th order
Statistical assessment	Max of all measurements per power bin	95th percentiles of all measurements per power bin	95th and 99th percentiles for each 24h
Parameter	Current	Current	Current / Voltage

TABLE III. Example of transferability of harmonics measurement results between two PGUs

PGU	Parameters effecting harmonics	Example of transferability
WTG1	Rotational speed, switching frequency of converter, generator, etc.	If rotational speed of WTG1 > WTG2 then measurement report from WTG1 can be transferred to WTG2 conservatively
WTG2		
PV1	Switching frequency of inverter	If switching frequency for PV1 > PV2 then the measurement report from PV2 can be transferred to PV1 conservatively
PV2		

B. *Measurement of DC current injection*

Measurement of DC current injection and subsequent data analysis can be performed according to IEEE standard 1547.1 [18]. There are no international grid codes which require this measurement at present. However UL suggests that PGUs which includes a unit transformer as a part of the PGU may be relieved from this requirement.

C. *Testing of control requirements*

Control requirements like FRT, frequency response, active and reactive power capability during FRT are defined in most international grid codes however the specific limits or associated voltage or other electrical parameter functions may differ. Few examples of differences between the FGW guidelines and CEA regarding control requirements are given below:

i. *LVRT:* according to the FGW requirements has a different limit than the CEA requirement [12] as illustrated in Fig. 1.

ii. *Frequency response:* FGW regulations define the frequency variation as a function of active power, while the CEA does not define such an exact mathematical function.

iii. *Reactive power during LVRT:* FGW regulations define a function of the reactive current during LVRT events, while the CEA does not define such an exact mathematical function, only that it should be maximized.

However, if we have an unit certificate according to FGW technical guideline 4 (TG4) [8], it means that the PGU has a validated software model. Model validation means that the software model's dynamic behavior is exactly similar to the PGU in reality. Therefore instead of performing new tests for specific CEA limits on the control behavior, a software simulation with the validated model and the events as defined by CEA should also prove the behavior of the PGU with sufficient accuracy.

V. Conclusions

In this paper, an alternative certification procedure for grid compliance of all types of PGU (including wind turbines and inverter-based generating stations) in accordance to the latest CEA requirements (2019) is proposed. According to this alternative procedure specific suggestions and recommendations for processes for example on how the test results from a different PGU model can be evaluated to verify if parts of the existing test and evaluation is technically comparable to the PGU under certification or not, how to transfer test results to other PGU variants, how to use software simulations to verify certain control requirements of the CEA 2019 [12] are provided. Additionally it is recommended that the measurement reports that will be evaluated under the certification procedure shall follow the latest international standards and guidelines, like the IEC 61400-21[5] or IEC 61400-21-1 [6], regarding the testing procedure.

The proposed procedure should facilitate grid compliance of PGUs according to requirements of the CEA 2019 [12] and more make it more efficient in terms of utilization of available measurement and evaluation work.

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