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संदर्भ संख्या : पोसोको/रा.भा.प्रे.कें./कें.वि.वि.आ. दिनाँक: 30th June 2017

सेवा में,

सचिव,
केंद्रीय विद्युत विनियामक आयोग,
तीसरी मंजिल, चंद्रलोक बिल्डिंग,
३६ जनपथ, नई दिल्ली -११०००११

Sub: **POSOCO's comments on Draft Central Electricity Regulatory Commission (Transmission Planning and other related matters) Regulations, 2017**

Ref: **Public notice dated 26th April 2017 and 05th June 2017 by Secretary, Central Electricity Regulatory Commission regarding uploading of Draft CERC Transmission Planning and Other related matters regulations, 2017, and inviting comments from the stakeholders**

महोदय,

With reference to the above mentioned notices of the Hon'ble Commission, the views/suggestions of POSOCO on behalf of all RLDCs/NLDC on the draft are enclosed herewith for you kind perusal.

सादर धन्यवाद,

भवदीय

स. उपर्युक्त

एस आर नरसिम्हन

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30th June 2017

Sub: POSOCO's comments on Draft Central Electricity Regulatory Commission (Transmission Planning and other related matters) Regulations, 2017

Ref: Public notice dated 26th April 2017 and 05th June 2017 by Secretary, Central Electricity Regulatory Commission regarding uploading of Draft CERC Transmission Planning and Other related matters regulations, 2017, and inviting comments from the stakeholders

1.0 Introduction:

A consolidated regulation in the matter of administrative issues in Transmission planning in Indian Grid in backdrop of changing scenario of power system on account of high growth, integration of large amount of renewables in the grid, need for margins in grid operation, among others, was highly desired. The aim of regulation to take necessary steps required for change in planning scenario to synchronise between licensed activity of Transmission and Open access, and delicensed activity of generation, will have far-reaching consequences for the power and energy sector and the country as a whole.

In planning and developing the transmission system, a top-down approach has mostly been followed so far. The present draft regulation attempts to revise this process by recommending a bottom-up approach, which is a welcome change.

Some of the issues that need to be considered in finalizing the Draft regulation are outlined below.

2.0 Reliable operation of power system with a resilient transmission system involves thorough planning in both operational and planning horizons. The planning of transmission system demands extensive power system simulation studies like load flow study, voltage stability study, small signal stability study, transient stability study and electromagnetic transient study. Apart from these, several specific studies like Islanding, Sub-synchronous study, Ferroresonance, protection coordination, Insulation level etc. also need to be carried out. Quality models that represent the actual system quite accurately will help the planner in better analysis and optimum utilization of the resources.

Accurate modelling of power system components like generators, exciters, governors, Power system stabilizers, over-excitation limiters and under-excitation limiters, transmission lines, SVCs, HVDC terminals, loads, Wind plants, Solar plants, Auxiliaries, etc. require submission of quality data by the equipment owner(s) to planners.

The present framework of regulations in Indian power system does not cover adequately the submission of necessary data for modelling. Format-CON-4 of CERC approved Detailed procedure for connectivity to the grid under Regulation 27(1) of CERC's (Grant of Connectivity, Long-term Access and Medium-term Open Access in inter-State Transmission and related matters) Regulations,2009, lists out information to be submitted by generator in the planning phase to CTU for purpose of modelling. But the information submitted by generator as part of the Connectivity agreement with CTU is often inadequate in accurately modelling the generating station components. Besides, it does not include mandate for furnishing data pertaining to a plethora of other power system components.

It is thus felt necessary that the CERC's Transmission Planning Regulations, 2017, may mandate furnishing of detailed modelling information by owners of power system equipments, which further need to be validated and verified by the planners.

Power system reliability councils like WECC in USA maintain repository of models for power system components. The scope of Central Repository of Generators, as suggested for creation in this Draft regulation, may be widened to include detail models of power system equipments as well.

The detailed procedure to be brought out by CEA as per clauses of this regulation may list detailed models of power system components and other relevant details, as required for modelling.

A report was developed by NLDC/RLDCs to address the concerns above, titled "Report on Model data submission and validation in Indian Power system" may be referred in this regard. Copy of the report is enclosed as ***Annexure-I.***

Section 3:

Following definitions may be added:

- **National Study Committee on Transmission Planning:**

- **Model Verification:** Refers to the process of verification of both static and dynamic models of power system elements at the time of submission of modelling information to ensure that the model accurately represents the physical element's logical structure and behavior. The model verification for generating units shall include but not be limited to generator, excitation system including over-excitation and under-excitation limiters, turbine governor, and power system stabilizers. Modelling of transmission elements shall include but not be limited to transmission lines, transformers, SVCs, FACTS devices, HVDC lines, primary protective equipment like Distance protection relays. Modelling of loads shall cover representation of different load types from incandescent lamps to induction motors and power electronic loads etc.

- **Model Validation:** Refers to the process of benchmarking of the models of power system elements from time to time by comparison of simulated dynamic response with field measurements. Periodic model validation is expected to take care of changes in the physical element on intended and unintended modifications (Ageing, Wear and tear, etc.).
  Although planning system models cannot be directly validated against field measurements, parts of the planning model that represents existing facilities should match with the corresponding validated operations model.

3.0 **Section 8.2(a) :** May specify…"Preparation of basecase of the state ***in standard PSSE format****…"*

4.0 **Section 9(1) :** NLDC provides Operational feedback to CEA/CTU inclusive of operational statistics on Quarterly basis, as per section 4(j) of NLDC Rules 2005. The same may be explicitly mentioned here. Considering that standing committee meetings will be conducted quarterly, present periodicity of Operational Feedback by NLDC / RLDCs should suffice the reporting requirements being indicated as per Draft Regulation. The feedback is available in the public domain and can be accessed by all at https://posoco.in/documents/operational-feedback-on-transmission-constraints/ .

5.0 **Section 9(2) :** Does this amount to providing Operational Feedback (includes all operational issues and suggested remedial measures) to central study committee as well? As stated above, the NLDC operational feedback is already available in the public domain.

6.0 **Section 10 :** Operational issues flagged by RLDCs are already included in NLDC's quarterly operational feedback document as stated above. There might be little need for another level of feedback to central study committee from RLDCs.

7.0 **Section 11 :** The periodicity and timeline of feedback by SLDCs may be specified. Ideally this feedback may be synchronised with that being provided by NLDC / RLDCs. Feedback from SLDCs may be given to RLDCs, who in turn can flag the operational issues / statistics of SLDCs in RLDC's Quarterly Operational feedback. Accordingly, SLDCs may provide feedback around 1 month prior to the reporting date by RLDCs / NLDC. Same feedback can be forwarded to Regional study committee, thus eliminating need for additional levels of reporting. SLDCs would in any case send such a feedback to the respective STUs.

8.0 **Section 12(1):** Transmission planning regulation should take care of the requirements in view of change in energy mix (i.e., more quantum of renewables in generation mix). Accordingly, all RE generators of 10 MW and above capacity (RE farm with a lead generator) may be mandated to provide Technical data for modelling.

Format for furnishing technical details may be kept common for Central and Regional level to prevent hindrance in information exchange.

The details specified by generators must be Verified by Central / Regional study committee before acceptance. For consideration in studies, model validation is also necessary.

9.0 **Section 12(2):** Technical details of a generating plant like machine inertia, leakage reactances, etc. are likely to vary over the lifetime of generator due to change in ambient conditions, wear & tear etc. Accordingly, every 3 years, generators may submit updated technical details that need to be validated by Central/ Regional study committee.

Central Study committee may maintain a repository of Dynamic Models of generators. Further in case of studies for subsynchronous resonance, the generator may be required to submit more detailed models at the turbo generator level.

10.0 **Section 15(d) :** Frequency of meetings could be mentioned

11.0 **Section 16(a):** For preparation of state-wise system study files, inputs would be required from DISCOMs (in regard to type of loads, Distribution of load growth in different areas of the state), SLDCs (in regard to existing operational network, Estimated load growth). So, DISCOMs and SLDCs need to provide requisite inputs to STUs.

12.0 **Section 17(c):** Timeline for preparation of procedure by CEA need to be mentioned. CEA may involve NLDC / RLDCs / CTU/ STUs/ SLDCs in formation of the procedure to involve all stakeholders.

13.0 **Section 17 (f)** may be added as **'Generators should provide the complete details for modelling of their generators in the planning study tools in the required format by CEA. Further, these details submitted should be validated based on the testing by external agency whose periodicity** should be specified in the Detailed Procedure to be prepared by CEA.'

14.0 **Section 20.2:** May add "Interaction amongst nearby HVDC terminals and interaction of HVDC terminals with AC system". In respect of gas turbines and hydro generators, black start capability, dead bus charging as well as charging of the transmission line from the black start generator may also be studied from the view point of resilience of the system. Reactive power compensation should duly factor such conditions.

15.0 **Section 23.1 (b):** Different STUs/ SLDCs may have different methodology in Demand projections. In absence of a common guideline, the projections could vary widely, thus lacking credibility. A common guideline for demand projection (including projections of Load growth, type of load, nodal distribution of loads) may be developed by CEA in consultation with CTU / NLDC / RLDCs.

16.0 **Section 23.1 (c):** It is likely that SLDCs would be able to provide a better estimate (including information regarding upcoming CPPs, etc. in the state) of projected load / generation for purpose of transmission planning. Thus, the projection may be done by CTU in consultation with SLDCs / RLDCs / NLDC / CEA**.**

17.0 **Section 25.1 :** Change to "operational feedback provided by NLDC / RLDCs and SLDCs…" instead of "operational feedback provided by RLDCs and SLDCs"

18.0 Section 26.1 :

In table, under Activity, Sl.No. 2 (Lower half)=> "Operational issue to be submitted by NLDC / RLDCs / SLDCs…" instead of "Operational issue to be submitted by NLDC/RLDC…"

19.0 To be added suitably in section 23:

(1) For each of the proposed transmission plans, CTU shall give at least 3 options. These options shall be evaluated based on techno-economic analysis.

(2) All the proposed transmission plans shall be accompanied with the following studies results:

- Dynamic Power Flow Study
- Interconnection Study
- Steady State Power Flow Study
- Short Circuit Study
- EMTP Studies
- Point of Connection Charges Study
- Studies for special cases such as Subsynchronous Resonance (SSR)
- All other studies specified in the CEA (Technical Standards for Connectivity to the Grid) Regulations, 2007.

20.0 While generators have been made mandated to register in the Central Repository of Generators, a depository of DISCOMS should also be developed wherein each distribution company would be mandatorily required to furnish relevant information such as existing and prospective load centres, projected growth of load in terms of import through 132/33kV and 220/132kV S/Stns of the STU system, in short and long term etc.

21.0 Each SLDC should conduct monthly / quarterly meetings with its DISCOMS, where such repository should be regularly reviewed and updated. In case distribution companies fail to periodically update their respective database, it should be reported by the concerned SLDC to CEA and CERC.

22.0 STUs have been inter-alia made responsible for preparing base case of the state for Transmission Plan. This in turn requires that each STU should have the updated base case of the entire national grid modelled up to intra-state level. Therefore CTU shall have to take the responsibility of making such updated base case available to every STU.

23.0 At present, the procedure followed by different STUs in granting connectivity and LT/MT access to various intra-state customers is not clear. It is felt that there is a need for developing a uniform basis for granting connectivity and access.

24.0 In many STU networks, the load catered (through 220/132kV ATRs) is supplied radially, with no scope for (n-1) security either in the upstream 220kV system or of the 220/132kV ATRs or of the downstream132kV system. Further although (n-1) security may not be apparently satisfied at 220kV level or by 220/132kV ATRs or by 400/220kV ICTs, some of the states have implemented inter-tripping schemes within the STU network for load rejection and prevention of cascade tripping, on occurrence of an (n-1) contingency. It needs to be decided whether such practices should be continued in lieu of ensuring transmission adequacy.

25.0 Usually it takes around 18-24 months for implementation of an ISTS scheme, after approval by Standing Committee and RPC. However, after significant investment has been made by the CTU / transmission licensee, it may become apparent that either the expected generation or the expected demand would not be in place by the time the ISTS gets ready. In such case, utilization of the ISTS system after its implementation cannot be expected to be satisfactory. Endeavour should be made to minimize such cases. In particular, the generator developer(s) or the DISCOM(s) should be made accountable for substantiating the reasons for the gap w.r.t projections, with supporting documentary evidences.

26.0 It would be desirable to define composition of Regional and National Standing Committees in the Regulations. Respective RLDCs should be members of Regional Standing Committees.

27.0 If the ISTS is undertaken through TBCB as decided by Empowered Committee, Bid Process Coordinator has to sign TSA with Regional beneficiaries which consume lot of time. Now as per the draft Regulations, there would be regulatory approval of all new transmission assets after finalization in National Standing Committee where objections/suggestions of stakeholders would be considered. Taking this into account, signing of TSA by BPC would be duplication of activity and should be dropped.

Moreover, NEP and Tariff Policy specify that CTU/STU should undertake network expansion after identifying the requirements in consonance with the National Electricity Plan and in consultation with stakeholders, and taking up the execution after due regulatory approvals and prior agreement with beneficiaries would not be a pre-condition for network expansion. This aspect may be mentioned in the Regulations.

28.0 In the scheme for certification of personnel involved in planning, all agencies involved in planning process should be included.

29.0 Transmission planning study involves collection of various data, their analysis, modelling and integration into system study case and then the simulation and crafting out the planning from these studies. This requires continuous and rigorous training with the changing scenario. The System study needs experts in load flow/transient, voltage and small signal stability/System protection scheme study. Apart from these as the system is becoming complex and various specific studies carried out by consultants like SSR/POD tuning etc. also need to be understood by the planners before implementation. All these require specific training to the manpower deployed for the planning study.

30.0 Any system specific studies due to increasing complexity in the system as and when desired and be carried out by outside experts/consultants should also be decided by the national and regional committee. The modalities on the funding required for these studies should also be decided by the CEA and CTU.

31.0 In case 1. Correct data is not provided 2. Incorrect data is provided by the Generator to CEA/CTU by the specified timeline, CTU/CEA may approach CERC for enforcing of Regulations.

32.0 For a rigorous planning process, the system studies must be preceded by a production cost modeling and simulation covering 8760 hours of the year. This requires high quality time series data at a minimum of hourly resolution so that even the quarterly snapshots taken by CTU for studies are as close to reality as possible. SLDCs, RLDCs and NLDC must be mandated by Planning Regulation to provide time series data at hourly resolution for the following minimum parameters:

32.1 District wise and DISCOM wise load, state load, hydro and Renewable Energy (RE) generation at intra state level by SLDCs as recorded by the Energy Management Systems (EMS)

32.2 State wise and region wise loads, hydro and RE generation at the regional level as well as import by the state from ISTS as recorded by RLDCs in their EMS

32.3 Region wise and All India loads, hydro and RE generation at an All India level as well as inter-regional and cross border exchanges as recorded by NLDC in their EMS.

Access to the above data could be provided to stakeholders through a username and password after authentication of credentials.

In a similar manner, the CEA and CTU must provide access to the study files to stakeholders after due authentication of credentials. In fact providing access to such data could also be advantageous if CEA wishes to selectively invite suggestions through the Swiss Challenge method for planning any new infrastructure.

33.0 While considering the operational feedback by NLDC / RLDCs, the Study Committees must also make an assessment whether anything went wrong with the planning process and improvements possible.

ANNEXURE-I

Report on Model Submission, Verification and Validation for Indian Power System

POSOCO

Version: 1.0

Date: 27-01-2016

Index

Acknowledgement

This report is a culmination of collective efforts and contribution of a large number of engineers within POSOCO. The valuable contribution by each and every one of them is highly appreciated and acknowledged. Special acknowledgements to the persons involved in System Study group and Analysis group at each RLDCs and NLDC for contributing to the subject matter in this report. POSOCO also acknowledges the contribution of eminent experts from India and abroad whose valuable insights during the course of several years of interaction have helped in understanding the importance of model submission, verification and its validation.

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The work of this taskforce has started on 21-05-2015 and completed by 31-12-2015 with a series of discussions on various topics related to the report. The taskforce team members highly appreciates the efforts SRLDC, SRPC and Generating station in Southern grid for the Reactive power testing experience sharing which has helped in formulation of the use case for this report. The team would like to thanks all the Senior Members of POSOCO who have continuously guided and shown the path during this formulation of this report with their enriched experience and knowledge.

1 Introduction

Any power system planning and its reliable operation require a large amount of data in order to study and analyze the various condition under which the power system has to operate. This data requirement varies at different stages of planning and operation. If we consider the technical stage of planning and operation of power system, then it requires model data for various power system equipment in order to study their dependability on each other. As the power system is a non-linear system so it is essential to analyze this non-linear aspect in time and frequency domain studies with the help of a non-linear standardized model of the system. Such type of studies consists of load flow study, voltage stability study, small signal stability study, dynamic stability study and electromagnetic transient stability study. Apart from these several specific study like Islanding, Sub-synchronous study, Ferroresonance, protection coordination, Insulation level etc. are also required to be carried out. So, a good quality of data which represent the actual system quite accurately will help us in better analysis and optimum utilization of the resources.

In the recent year's challenges in real time operation of Indian Grid has increased manifold with the meshed network, multiple voltage levels, large sized units, large generating complex, multi-terminal HVDC etc. Further, the operator has to optimize the system in a balanced way to ensure power system stability in one hand and economic dispatch in other. The secure operation will always require accurate power system model on which various studies can be performed in the online/offline mode to ensure system security under economic dispatch for various conditions. This signifies that these models are the very foundation of virtually all power system studies. Starting from the calculation of operating limits, planning studies for assessment of new generation and load growth, performance assessments of system protection schemes (SPS), performance study of new SPS schemes, system dynamic behaviour under transients etc.– All such studies depend on an approximate mathematical representation of the complete generation, transmission, and load in the system.

Among the various task for system studies, first comes the model submission part whose situation is also quite worrisome in India as many times the model are also not being submitted by respective utilities which results in the use of standard planning model. The standard planning model results in over/under optimistic study especially under transient and small signal stability studies. The regulation for submission for detailed planning model and operational model for power system component in Indian Power system is yet to come in shape along with its compliance provision. This has resulted in various gaps observed in the data submission. There is immediate need for such regulation in order to enforce the utility for providing such information based on which planner/operator can perform studies. Further, the need of modelling subcommittee at national and state level is also a long sought exercise which is yet to take place in India.

The next step after the model submission comes is the verification of such model. These verification are also required to be done first at utility level followed by planners/operator level prior to its use. Sometime the bad model may result poor results which is of no use to operator. For such activity also, there is a need of sub-committee which can help in fine tuning of the various submitted models. Good model provide better results which helps in various kind of studies.

However, the performance of these approximate mathematical models need to be regularly compared against actual measured power system data. This exercise is called as model validation. The lagging in the model validation frontier will result in over/under optimistic system behaviour. The worrisome question that comes with this is that if the power system model does not represent observed phenomena on the power system with reasonable accuracy, then how can one have confidence in studies derived from that model? This is faced in across all the countries across the world. Many of them has started working in order to improve their modelling to get near real time results.

So, there is a need to access the requirement of model submission and validation along with the national and global perspective. In order to achieve this, POSOCO has prepared this report as the first step. This report basically emphasizes why such models are required, how it impacts the security of Indian power system and how it can be achieved. A case study on Model validation of Reactive power capability of generating station in Southern region is also presented. The case study provides the input how such validation helps during operational horizon. Further the “Report on Low Frequency Oscillation in Indian power system” by POSOCO has also shown that how the actual data from generating end provide a good overview of the system during studies and help in validating it with system response [1].

This report is intended to be utilized for taking actions with regard to improvement in the area of Model submission and verification the Indian power system. This report is also a feedback from Power system operator fraternity across India in regard to various challenges being faced by them which should have been addressed at regulatory and planning level. The report not only highlights the issues, but it also attempts to solve these problems based on the Indian as well as global perspective. The report has been sectionalized in Model data submission, Model data validation and the case study on model Validation in Southern Grid.

2 Model Data Submission Criteria in India and Across the Globe

2.1 Introduction

Power system operation is based on the simulation of the electrical grid, which can be done with the state estimator in real time. Further, operational planning is also done based on offline studies using simulation software based on near real time data. On the other hand, power system planning is based on the offline simulation using futuristic data from various sources. However, both the operation as well as planning requires a better model of the complete system in order to get accurate result for highest efficiency. In view of this, the model data submission is very essential from the angle of planners and operators for improving the system reliability during planning and operation horizon. This chapter will bring out the various criteria, which is being followed across the world for submission of data during planning and operation of electrical grid in the India and world. Further, this will help in highlighting the area that need to be utilized for Indian power system operation.

2.2 Types of Power system Simulation data

There are three types data requirement for power system simulation for planning and operation. First of them is steady state data for load flow study, second is dynamic model data for transient study and the third is short circuit data for short circuit and fault study. These data can be further categorized into two category i.e. **Planning data and Operational Data**. Planning data is used in planning exercise and is updated with operational data when the planned system is in place. So, it may have several assumptions due to its futuristic need and may not be a very large data set. However, Operational data is a large data set which consist of validated model data for the studying the power system during operational horizon. Several of the Regulators/Planner/Operators across the world have defined the procedure/standard/regulation regarding the above two sets of the data. This has been done in order to use actual system for futuristic planning and near actual system for operational purpose.

In order to have a consistent model requirement for planning and operational purpose, there is need of exercise in designing the model specific requirement according to the Software used for planning/operation. Further, there is also a need of criteria for model verification criteria in order to cross check the usability of the model. So, as a first step there is need to appreciate the requirement of model submission and understand why accurate model is required for planning and operation. Also the awareness regarding what could go wrong with standard model utilization or incomplete model need to be explained. This will help in knowing about the model submission criteria genesis across the world. The next section briefly explains the various issues related to bad modelling through global experience, which has severe impact.

2.3 Need of Model Submission and their Verification and Validation

Various countries around the world have specific regulations/procedure/standard/Policy for model data submission for power system planning and operation. It has been a practice to utilize the standard model for power system planning and operation. However, the adverse effect of such standard model has a long-term impact on the grid. The need for actual model data is the core of both planning and operation. Yet the question remains why we need such accurate data? In this section, it has been tried to find the reason behind such gradual change in the world in terms of model submission and model verification and validation.

The utmost question that comes in into play is that what benefit a Planner/Operator get from the verified and validated model of the various system component. The very answer to such question lies in the famous Blackouts in the world. Power System Disturbances in the world commonly called as blackouts have driven out the various reforms, which are required in the power system across the world. Larger blackouts in the world have shaped the electrical industry and their modernizations in order to provide more security and reliability.

The Extract from the August 14, 2003 USA and CANADA Blackout report is reproduced below concerning the challenges faced during the recreation of event in simulation model by the Task force [2] :

"The after-the-fact models developed to simulate August 14 conditions and events found that the dynamic modeling assumptions for generator and load power factors in regional planning and operating models were frequently inaccurate. In particular, the assumptions of load power factor were overly optimistic—loads were absorbing much more reactive power than the pre-August 14 models indicated. Another suspected problem concerns modeling of shunt capacitors under depressed voltage conditions. NERC should work with the regional reliability councils to establish regional power system models that enable the sharing of consistent and validated data among entities in the region. Power flow and transient stability simulations should be periodically benchmarked with actual system events to validate model data. Viable load (including load power factor) and generator testing programs are necessary to improve agreement between power flows and dynamic simulations and the actual system performance." (Reference: U.S.-Canada Power System Outage Task Force Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations page 160)

The taskforce recommended that FERC and appropriate authorities in Canada require all generators, regardless of ownership, to collect and submit generator data to NERC, using a regulator-approved template. Further, it also recommended the validated modeling data shall be exchanged on an inter-regional basis as needed for reliable system planning and operation.

The above recommendation have driven the electrical industry in USA and Canada and changed the complete scenario. This has left it embarks in the area of power system modelling, verification and validation.

Other examples of such blackout can be WSCC blackout in August 10, 1996 [3-4]. Figure 2.1 shows the comparison of actual and simulated event which itself depicts the need of correct model

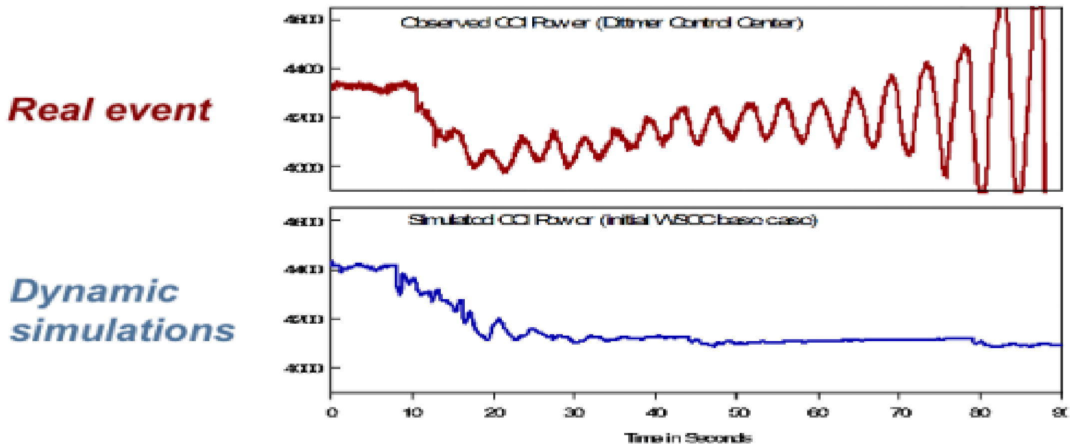

Figure 2.1: WSCC August 1996 Outage: Actual event and the simulation that showed what planners expected would happen. (www.smartgrid.gov/files/NASPI_model_validation_ workshop.pdf.)

Separation of Alberta System on August 4, 2000 due to poorly damped mode in the system is another event which deliberated the need of correct model and its validation. The event is shown in figure 2.2 where the undamped oscillation impact on system is clearly observed to be catastrophic.

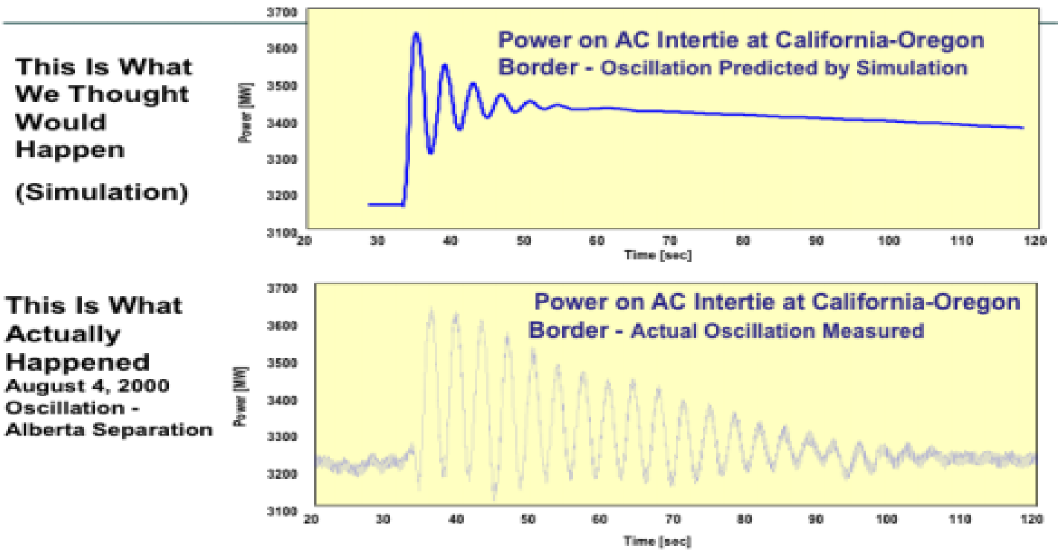

Figure 2.2: August 4, 2000 Oscillation that led to the separation of Alberta from the rest of the Western grid (www.smartgrid.gov/files/NASPI_model_validation_ workshop.pdf.)

North American Synchrophasor Initiatives (NASPI) has organized a model validation workshop on October 22, 2013 [5]. The workshop highlighted the importance of model validation in power system planning and operation. The details can be found on following links www.smartgrid.gov/files/NASPI_model_validation_ workshop.pdf.

The impact of incorrect model in power system has severe repercussion, which is listed below in view of Indian power system:

1. Unexpected system behavior compared to model system. (e.g. System Response on July 2012 blackout, presently no dynamic model validation of the system for the blackout has been done)
2. The Impact of system component, which are not adequately model is missed and its interaction with other model is not observed. (Non-availability of models of STU connected generators, Governor/Exciter/PSS of CTU connected generators/Zone 3 tripping on Load encroachment/Governor response in Indian power system)
3. If something in not modeled, predicting the system behaviour or the interaction of components is not possible? (0.2 Hz oscillation while interconnecting NEW-SR Grid) [6-9]
4. Bad modeling can give a false sense of security (Several cases of undamped oscillation/Power swing causing UMPP blackout)
5. Bad modeling causes bad decisions: In planning, it means wasted money while in Operations it means insecure operation. (Non-utilization of POD of HVDC/TCSC due to continuous change in the network architecture)

Now what could be gained with better system model in Indian power system can be best explained with following points:

1. Planners/Operators know the inherent challenges of the actual power system.
2. Remedial action planning can be done in better manner.
3. In-depth insight provides heighten system security
4. Potential for effective and optimum asset utilization
5. Effectively integrate resources and composite loads - technology and characteristics evolve
6. System response for various stability.
7. An effective way to design the SPS in the power system for system security.

These are among the few of several benefits of the validate model utilization for power system planning and operation. This is the very reason behind the several numbers of regulation/standard/procedures/policies formulated and implemented in various countries for model submission and its verification & validation. To initiate such an exercise in Indian power system, a review of the various criteria for model submission has been described in the next section.

2.4 Criteria for Model Data Submission in India

In Indian power system, criteria for planning model data submission at central level is not clearly stated in the grid code or any other regulation. However, the central transmission utility has been permitted to derive the format for planning data requirement as a part of connectivity regulation. While in many of the State electricity grid code has described about the planning data from the users. However the Operational data requirement has not been clearly stated in any of the regulations. This section provide an overview of various regulations at central and state in India.

2.4.1 Central Level Data Requirement

In **Indian electricity grid code (IEGC)**, planning code for inter-state transmission is defined in part 3 [10]. Relevant cause on Planning and operational data are as following:

- **3.2. Objective:** The objectives of Planning Code are as follows: (c) to provide methodology and information exchange amongst Users, STU/SLDC and CTU/RLDC, RPC, NLDC and CEA in the planning and development of the ISTS.
- **3.4.d. Planning Philosophy:** All STUs and Users will supply to the CTU, the desired planning data from time to time to enable to formulate and finalize its plan.
- **3.6.a. Planning Data :** Under this Planning Code, the Regional entities/STUs/State Generating Companies/IPPs/licensees are to supply data in accordance with the detailed procedures mentioned in the Central Electricity Regulatory Commission (Grant of Connectivity, Long-term Access and Medium-term Open Access in inter-state Transmission and related matters) Regulations ,2009.

In the above regulation, the objective of information exchange has been defined however there is no clear instruction/procedure of information exchange amongst the user has been defined. Further the data defined are for planning purpose and there is no detail on the operational data requirement. Thus, operator is also using the planning data which deviates from the actual operational data in most of the cases.

In the relevant procedures for the Grant of Connectivity, Long-term Access and Medium-term Open Access in inter-state Transmission and related matters) Regulations, 2009, the planning data requirement is mentioned in Con-4 [11]. The feature of data mentioned for planning is as following:

- The above data set consist data requirement for Bulk power consumer (>100 MW) and Generating station connected with ISTS network.

- The data for bulk power consumer (Load) is slightly limited in nature as required for planning only.
- While for generator data, the model mention is limiting the data to thermal/hydro generator type (GENROU/GENSAL for PSS/E).
- Further provision of assuming of data by CTU when details are not provided for excitation system is also mentioned resulting in the incomplete set of data provided by generating end.
- The data for Governor and PSS has not been mentioned in the connectivity.
- The data set is fixed as one-time submission.

Thus, the above procedure defines for one-time requirement for data from Generators and Bulk consumer, however, there are several limitation in using the same data for future planning. There has to be a provision of data submission on regular basis which is missing or the interlinking between planning and operational data has not been clearly mentioned in regulation/procedure. The verification of the data is also not mentioned in the procedure which many times affect the complete study. In few cases the submitted data for dynamics were tested by POSOCO and it was found that they were having stability issue during simulation.

Further, as a part of such data requirement, the HVDC/TCSC/SVC and other devices remains out of scope of this procedure. In regard to carry out the study related to small signal stability, tuning of PSS/POD, sub-synchronous torsional interaction the regulation does not specifies the data requirement.

In terms of Point of Connection Tariff regulation, the steady state data submission to the operator has been defined which enables them in performing the load flow studies. However the dynamic data requirement is still a missing factor for operational studies.

It can be observed that submission of several type of data requirement and it’s timeline to power system operator has not been clearly demarcated in the regulation which is very much required. This will enable operator for accessing the actual data from generators, transmission agencies and bulk power consumers for system studies in the operational horizon. Further, it will also enable them in providing proper feedback to regulator/planners/users on the operational issues and remedial solutions.

2.4.2 State Level Data Requirement

In terms of data requirement, many of the state electricity grid code has defined the data requirement for planning purpose in detailed manner [12-29]. It was observed that two type of planning data has been described i.e**. Standard Planning Data and Detailed Planning Data.** The standard planning data enables the STU for observing the impact of upcoming element on the existing system in load flow analysis. While the detailed planning data enables the STU to perform load flow, dynamic and transient studies of the element on the power system. However exact details/format for data requirement for dynamic and transient data (Model specification) is missing for various types of devices. Further, State grid code have also specified the interval for resubmission of data and the policy for data exchange among the users. However they remain silent on data validation and verification. This again provide a gap between planning and operational data at state level. In table 1, list of grid code where data template has been defined is provided as summary.

Table 1: Summary of state grid code and data requirement

State Electricity Grid Code	Planning Data format given in Grid Code	Planning Data format decided by STU	Data resubmission	Agency
Bihar	Standard & Detailed Planning data	-	Yearly basis	STU
Chhattisgarh	Standard & Detailed Planning data	-	if change is there	STU
Gujarat	Standard & Detailed Planning data	-	Yearly basis	STU
JERC	Standard & Detailed Planning data	-	Yes, Yearly basis	STU
Karnataka	Standard & Detailed Planning data	-	Half-yearly basis	Transmission Licensee
Madhya Pradesh	Standard & Detailed Planning data	-	Time to time	STU
Punjab	Standard & Detailed Planning data	-	Yearly basis	STU
Rajasthan	Planning Data	-	Yearly basis	STU/SLDC
Tamilnadu	Standard & Detailed Planning data	-	Yearly basis	STU
West Bengal	Planning/Connectivity data	-	Not mentioned	STU
Assam	Standard & Detailed Planning data	-	Request by STU	STU
Delhi	-	Format by STU for Standard & Detailed Planning data	Request by STU	STU
Haryana	-	Format by STU for Standard & Detailed Planning data	Request by STU	STU
Jharkhand	-	Format by STU for Standard & Detailed Planning data	Request by STU	STU
Kerela	-	Format by STU for Planning data	Yearly basis	
Maharashtra	-	Format by STU for Standard & Detailed Planning data	Request by STU	STU

Uttarakhand	-	Format by STU for Standard & Detailed Planning data	Request by STU	STU
Uttar Pradesh	-	Format by STU for Standard & Detailed Planning data	Yearly basis	STU

So in this section, the data requirement for planning at the state and central level has been discussed given in the various regulation. In the next section, criteria adopted across the world has been discussed for global outlook.

2.5 Criteria for Model Data Submission across the world

In this section, a survey of various codes/regulation/standard/guidelines/criteria has been studied from several countries to find out the criteria for model data requirement at planning and operation stages. Further, how these data are being utilized at these two regime is also studied in order to know the accuracy involved. It was found that, describing the complete mechanism for data submission and its verification in various utility were almost matching and in order to best explain the same only the major criteria have been shown. This will help in focusing the attention that why there is such stringent requirement for data submission in the world.

It was observed that following utilities having specific documents for Steady state and Dynamic Data for planning and operation purpose: NERC,ENTOS-E, GEC, EIRGRID, AEMO, Croatia, WECC, SERC, Reliability first, TENNET, PowerWater, PJM, NYISO, NPCC, MRO, MISO, Manitoba Hydro, FRCC [30-53]. Out of these the major utilities prime requirement has been explained in this section to give an overview of the process.

2.5.1 NERC

MOD-010-0 Steady-State Data for Modeling and Simulation of the Interconnected Transmission System & MOD-012-0 Dynamics Data for Modeling and Simulation of the Interconnected Transmission System.

- The Transmission Owners, Transmission Planners, Generator Owners, and Resource Planners shall provide appropriate equipment characteristics, system data, and existing and future Interchange Schedules in compliance with its respective Interconnection Regional steady-state and dynamic modeling and simulation data requirements and reporting procedures as defined in Reliability Standard MOD-011-0_R1 and MOD-013-0_R1.
- The Transmission Owners, Transmission Planners, Generator Owners, and Resource Planners shall provide this steady-state and dynamic modeling and simulation data to the Regional Reliability Organizations, NERC, and those entities specified within Reliability Standard MOD-

011-0_R1 and MOD-013-0_R1. If no schedule exists, then these entities shall provide the data on request (30 calendar days).

The above two standard enforces the users (Here it includes the transmission/generator owner, Transmission/resource planners) for submission of the data to Regional Reliability Organizations, NERC, and those entities specified in the standard. Further to establish consistent data requirements, reporting procedures, and system models to be used in the analysis of the reliability of the interconnected transmission systems, the MOD -011 and MOD-013 are in place.

MOD-011-0 Maintenance and Distribution of Steady-State Data Requirements and Reporting Procedures & MOD-013-0 Maintenance and Distribution of Dynamic Data Requirements and Reporting Procedures

- Regional Reliability Organizations within an Interconnection, in conjunction with the Transmission Owners, Transmission Planners, Generator Owners, and Resource Planners, shall develop comprehensive steady-state data and dynamic requirements and reporting procedures needed to model and analyze the steady-state conditions and dynamic behaviour or response for each of the NERC Interconnections.
- Within an Interconnection, the Regional Reliability Organizations shall jointly coordinate the development of the data requirements and reporting procedures for that Interconnection.
- **Steady Data Requirement:** Bus, Generating Units (including synchronous condensers, pumped storage, etc.), Transmission Line or Circuit (overhead and underground), DC Transmission Line (overhead and underground), Transformer (voltage and phase shifting), Reactive Compensation (shunt and series capacitors and reactors), Interchange Schedules.
- Steady State data includes all the parameters used during load flow analysis.
- **Dynamic Data Requirement :**
    1. Design data shall be provided for new or refurbished excitation systems
    2. Unit-specific dynamics data shall be reported for generators and synchronous condensers (including, as appropriate to the model, items such as inertia constant, damping coefficient, saturation parameters, and direct and quadrature axes reactances and time constants), excitation systems, voltage regulators, turbine-governor systems, power system stabilizers, and other associated generation equipment.
    3. Device specific dynamics data shall be reported for dynamic devices, including, among others, static VAR controllers, high voltage direct current systems, flexible AC transmission systems, and static compensators.

4. Dynamics data representing electrical Demand characteristics as a function of frequency and voltage.

The above two standards are for the detailed list of data that has to be submitted for planning and operational requirement of bulk power system. The data submitted should be either of the equipment installed or a typical manufacturer's data of the equipment of similar design and characteristics. However, the validation of the data along with short circuit data requirement and data for new technology like wind and solar generators has been missed and the same has been included in the MOD-032-1 and MOD-033-1.

MOD-032-1 : Data for Power System Modeling and Analysis

- Each Planning Coordinator and each of its Transmission Planners shall jointly develop steady state, dynamics, and short circuit modeling data requirements and reporting procedures for the Planning Coordinator's planning area.
- Each Balancing Authority, Generator Owner, Load Serving Entity, Resource Planner, Transmission Owner, and Transmission Service Provider shall provide steady state, dynamics, and short circuit modeling data to its Transmission Planner(s) and Planning Coordinator(s) according to the data requirements and reporting procedures developed by its Planning Coordinator and Transmission Planner.
- Balancing Authority, Generator Owner, Load Serving Entity, Resource Planner, Transmission Owner, or Transmission Service Provider : Provide either updated data or an explanation with a technical basis for maintaining the current data

MOD-033-1 : Steady State and Dynamic System Model Validation

- Each Planning Coordinator to implement a documented process to perform model validation within its planning area.
- The Reliability Standard requires Planning Coordinators to implement a documented data validation process for power flow and dynamics. For the dynamics validation, the target of validation is those events that the Planning Coordinator determines are dynamic local events. A dynamic local event could include such things as closing a transmission line near a generating plant.
- Comparison of the performance of the Planning Coordinator's portion of the existing system in a planning power flow model to actual system behavior, represented by a state estimator case or other Real-time data sources, at least once every 24 calendar months through simulation.

- Comparison of the performance of the Planning Coordinator's portion of the existing system in a planning dynamic model to actual system response, through simulation of a dynamic local event, at least once every 24 calendar months (use a dynamic local event that occurs within 24 calendar months of the last dynamic local event used in comparison, and complete each comparison within 24 calendar months of the dynamic local event).

The above two standards have clearly specified that planning should be done on the system which represent the actual system and its responses. Further, any data submission should come with reason and any change in behavior of equipment over the time should be submitted when the simulation and actual system behavior is varying.

2.5.2 ENTSOE: Network Code

- The Relevant Network Operator in coordination with the Relevant TSO shall have the right to require while respecting the provisions of Article 4(3) the Power Generating Facility Owner/HVDC Owner/ r to provide simulation models, that shall properly reflect the behavior of the Power Generating Module in both steady-state and dynamic simulations (50 Hz component) and, where appropriate and justified, in electromagnetic transient simulations.
- The models shall be verified against the results of compliance tests as given in the code. They shall then be used for the purpose of verifying the requirements of this Network Code including but not limited to Compliance Simulations given in the code and for use in studies for continuous evaluation in system planning and operation.
- For the purpose of dynamic simulations of Generators , the models provided shall contain the following sub-models, depending on the existence of the mentioned components:
    1. Alternator and prime mover
    2. Speed and power control
    3. Voltage control, including, if applicable, Power System Stabilizer (PSS) function and excitation system;
    4. Power Generating Module protection models as agreed between the Relevant Network Operator and the Power Generating Facility Owner, while respecting the provisions of Article 4(3); and
    5. Converter models for Power Park Modules.
- For the purpose of dynamic simulations of HVDC, the models provided shall contain at least, but not limited to the following sub-models, depending on the existence of the mentioned Components:
    1. HVDC Converter Unit models
    2. AC component models

3. DC grid models
4. Voltage and power control
5. Special control features if applicable e.g. Power Oscillation Damping (POD) function, Subsynchronous Torsional Interaction (SSTI) control
6. Multi terminal control, if applicable
7. HVDC System protection models as agreed between the Relevant TSO and the HVDC System Owner, while respecting the provisions of Article 4(3)

The ENTSOE Network codes have clearly set guidelines for the data required by system operator for network simulation for planning and operation. The ENTOSE network code has specific instruction for network simulation model and its validation with the response of actual system for all types of generating units in detail.

2.5.3 National Grid Code (NGC)

- Under the Planning criteria, two types of data to be supplied by users are called for Standard Planning Data and Detailed Planning Data.
- The detailed planning data if have any assumed value should be replaced with new estimated value after system energization.
- The steady state and dynamic data are to be submitted for demand, generators, and DC system as per the various requirements of planning code.

2.5.4 AEMO

AEMO has provisions for three types of data submission, which are Standard Planning Data, Detailed Planning Data and finally the Registered Data (pre-connection, post-connection). A Generator that connects a generating unit equal to or smaller than 30 MW or a number of generating units totaling less than 30 MW to a connection point to a distribution network will usually be required to submit less registered system planning data and less registered data. All the data are being then validated using model validation described under various testing criteria.

2.5.5 Croatian Grid Code

For the purpose of safe and reliable electric power system operation-TSO, DSO, Electricity generators and eligible customers shall submit and interchange required operating data.

2.5.6 EIRGRID

Dynamic Model Specifications for Users

- Users applying for connection to the Transmission System must provide the TSO with relevant dynamic models and supporting documentation.

- All models provided to the TSO must be usable. Models shall be intuitive, practical and not cause simulation problems.
- Models shall be suitable for inclusion in automated software. Model technical parameters shall also be consistent with the real physical values.
- The parameter ranges of the model (e.g. real and reactive power limits and range of allowable operating voltages) shall be consistent between load flow and dynamic models and shall be representative of the actual Users Plant.
- The model documentation shall clarify the range of short circuit levels for which the model is expected to perform to expected equipment behavior. If it is the case that the model will not represent performance problems under certain network conditions, then this shall be addressed in the model documentation provided to the TSO.

2.6 Summary

Based on the above regulatory and standard procedures survey along with the impacts of modeling on system planning and operation, it is well established that model data submission is very much essential and there is a need of separate regulation/procedure/policy for this in Indian power system. This is very true in terms that the economics and reliability in any system has its direct linkage with its accurate modeling. In the same context, the power system economic and reliability is dependent on its model and it helps in improving the system efficiency and reliability. These model based studies on accurate model are of more significant during the transient as standard model will not be able to reflect the various challenges of the grid which is observable in real time. In virtue of this, the model data submission for planning and operational purpose for all utilities/users shall be made mandatory and liability has to be imparted for the submission of any data as it affects the whole power system. This will help in improving the present condition of power system model in Indian Grid. However, it can be observed that there is a need of common census among all the grid codes for data submission at central and state level for planning as well as operational purpose. In order to achieve this, following is required:

- Common format for planning/operational data submission to STU/CTU/SLDC/RLDC.
- Specification of Model for data of Generators, FACTS devices and other power system elements.
- The timeline for data submission for various types of data.
- Verification criteria for submitted data.
- Exchange of data among different users/utilities/agencies.

So, the section has described the need of model data submission to planners and operators. However, the data submitted need to be tested based on actual system response which is called model validation. Two case study on model verification process has been described in the next section to showcase its importance.

3 Use Case for Model Verification

3.1 Introduction

The model are the heart of power system operation as it provide the crucial detail how the power flow pattern will be as per the law of physics. However if the model is not correct, it can also provide incorrect result which are not suitable in decision making process. This section discusses case of how bad data affects dynamic studies in power system analysis. It also showcases the need of model verification before using the model in the dynamic studies. Further the case of Small signal oscillation provided in “Report on Low Frequency Oscillation in Indian Power System” will also be discussed to some extent and it will be shown how it resembles the actual power system.

3.2 Validation of Power system Model for generators

Several number of models are being submitted by the incoming generators for modelling in power system simulation software as a part of the connectivity agreement. As these model are individual model which may be tested and simulated by the generators on different software, so there is always a chance of error when submitting details in the format prescribed by the utility. So, in order to best utilize the system, there is a need to first test run the submitted model and check the performance of model under various condition. This helps in detecting any bad data in the model creating numerical instability or system instability.

Let us take a large Unit data which was provided by the Generating plant for its generator, exciter and PSS in the prescribed format. However prior to using the model in day to day practice, it was first test run in the simulation software to verify the values. So, the submitted model was simulated in the PSS/E software to check the various parameter by creating a 3 Phase fault on the one of the outgoing lines from the generating station. It was observed that when the power system stabilizer (PSS) was switched on, the model has started oscillating while the no oscillation has been observed with PSS in switched off condition as shown in figure 3.1 and 3.2.

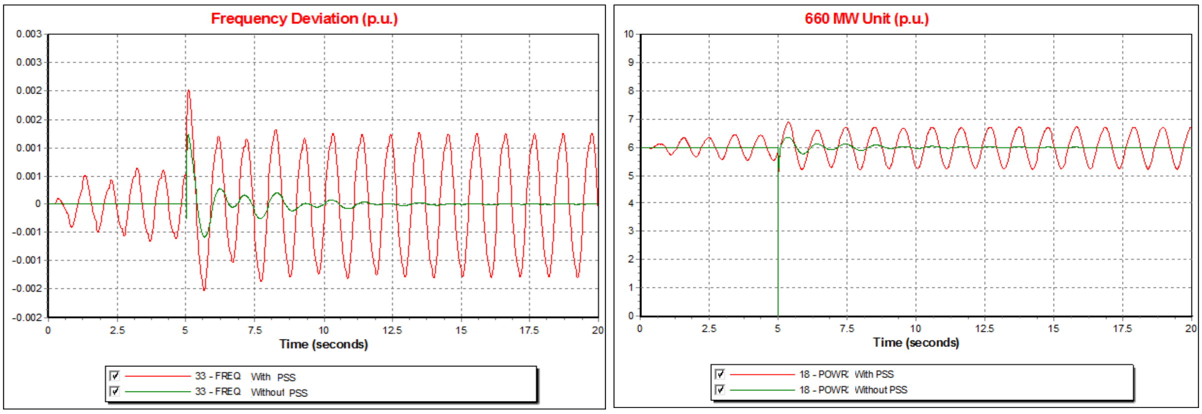

Figure 3.1: Frequency deviation response and unit output with PSS and without PSS for the simulated generator

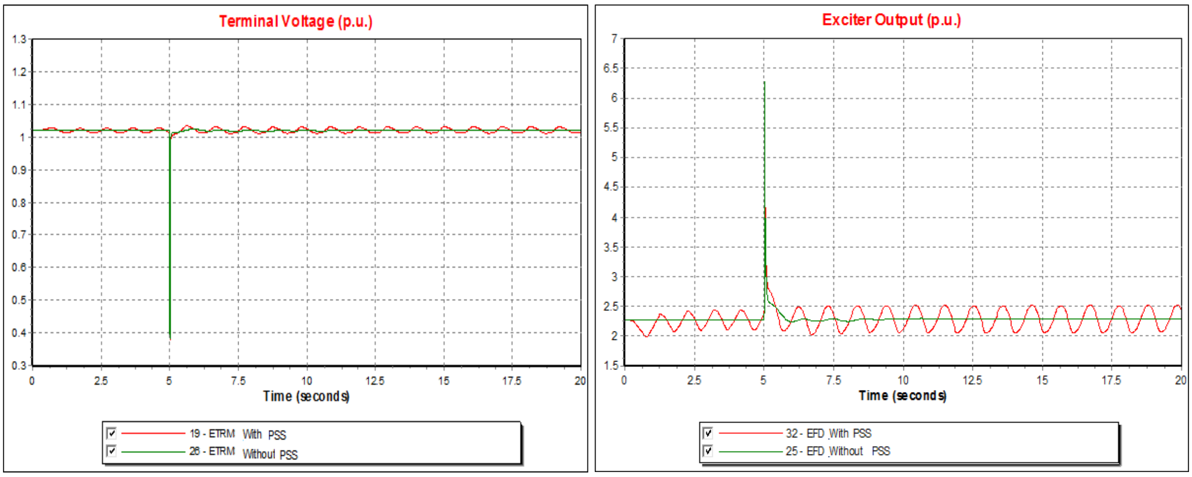

Figure 3.2: Terminal output and Exciter Output voltage with PSS and without PSS for the simulated generator

Then it was suspected that either the PSS detail is not correct with its parameters out of range or rather than damping it is providing a negative damping to the exciter resulting in oscillations. So, later the both the Exciter and PSS details were changed after investigation in the actual setting at the generators which is shown in table 1 and table 2 respectively. With the new setting the system became stable and performed as desired for various faults and system condition. Further, several other case studies also have been done on various model in order to verify the model. This helped a lot in getting good model which represented the generator to good extent. However there is still need for regulatory provision for getting the actual model from generators in order to reduce the level of such exercises which are cumbersome in practice. This will help in creating awareness at the generators end that how providing a bad model result in optimistic or wrong results. These data first need to be properly checked by the vendors who have provided the model to the utility.

Table 1: Old and New value of Exciter Model ESST1A

Model Name ESST1A					
Parameter	**Old Value**	**New Value**	**Parameter**	**Old Value**	**New Value**
TR (sec)	0.02	0.02	VA MAX	10	8.97
VI MAX	999	0.037	VA MIN	-10	-8.05
VI MIN	-999	-0.035	VR MAX	6.43	8.97
TC (sec)	0.8	1	VR MIN	-6	-8.05
TB (sec)	6	8	KC	0.038	0.038
TC1 (sec)	0	0.1	KF	0	0
TB1 (sec)	0	0.1	TF > 0 (sec)	1	1
KA	200	410.8	KLR	1	30
TA (sec)	0.003	0.003	ILR	0	4.1

Table 2: Old and New value of Exciter Model PSS2A

PSS2A Model for Stabiliser					
Parameters	**Old Value**	**New Value**	**Parameters**	**Old Value**	**New Value**
TW1 (>0)	**2**	5	T9	0.1	0.12
TW2	**2**	5	KS1	30	5.4
T6	0	0	T1	0.4	0.2
TW3	2	5	T2	0.6	0.03
TW4	2	0	T3	0.9	0.3
T7	2	5	T4	0.05	0.04
KS2 Gain	0.15	0.45	VSTMAX	0.05	0.05
KS3 Gain	0.5	1	VSTMIN	-0.05	-0.05
T8	8	0.6			

3.3 Verification of Power system Model

In order to check for the model verification of large power system, it is suitable to match the response of the model with the actual system. Though it is a part of validation if it is done for individual generators. However, if we check the larger system response like the frequency of inter-area oscillation or intra area oscillation and if it matches with actual system then system model is verified to some aspect. This exercise of model verification was done in the "**Report on Low Frequency oscillation in Indian Power System"** where intra-area mode in Western Regional Grid was verified. Such exercises helps in identifying that models are reflecting the large scale dynamic results within acceptable range. The small signal stability studies helps also in finding the out of limit parameters/generators which starts local oscillation causing model to go for dynamic instability. This has helped a lot in fine tuning of the bad models in the system.

3.4 Summary

So, here the case studies has shown why model verification is an important aspect after the model submission and there is need of regulatory provision and standards for such data submission. This will help in raising the view of the utility while submitting the models to planners/operators for planning and operational model of the grid. The next step for accurate modelling is the model validation which is basically the comparison of actual and simulated response of an equipment system and retuning of the model by either carrying out various tests. The next chapter basically describe the model validation criteria across the world and its requirement in Indian context.

4 Model Validation Criteria across the Globe

4.1 Introduction

Power system model formulation and their validations are important tasks and these form the very foundation of all power system studies. However, as it is known that the characteristic of generators and other power system element changes with time due to wear and tear. So, periodic model validation is necessary to have updated system model. This helps in optimum power system planning which need to be done based on the model which reflects actual system behaviour rather than assuming standard models for the existing system. Further, in order to have as better power system operation, the system operator should have power system model that provide near real time system rather than a standard model. Thus, it can be seen that the model validation is an important part of the power system modeling and its use for reliability and security of the electrical grid.

The objective of power system model validation is to understand the power system events so that their response can be appropriately provided by the power system studies. The ultimate goal of the model validation is to have a complete Indian grid model that can reasonably predict the response of an event. To achieve this, each individual model of the system component need to be validated with their response in the field.

In Indian Power system, the provision of model validation of power system component is not present in the regulations by CERC and CEA, which has led to the various assumption in the model resulting in a large gap between actual and simulated response during any event. Even the planning Criteria are based on the standard model usage rather than the actual field-tested data. This, in turn has led to non-validation of actual response of the 30th and 31st July 2012 grid disturbance by any entity in Indian power system. The complete understanding of the actual phenomenon, which has occurred during the grid disturbance needs the model, validated data of each component. The 0.56 Hz Low frequency analysis, which is included in this report, was also a herculean task as data of several generators were not present whose arbitrary assumption has led to a slight change in actual system response and simulated response [1].

This chapter briefs out the practices followed the globe across the model validation area. This will help in understanding the need of regulation on model validation in power system planning and operation.

4.2 Global Trend in the Power System model Validation

In order to capture the essence of the power system model validation requirement in any power system cross the globe, various planning codes, network codes, operational codes, regulatory approach of several countries were studied [30-53] . The section aims at crafting out the relevant extracts in order to give an overall view of the requirement of the model validation for Indian Power system.

4.2.1 NERC

MOD-024-1: Verification of Generator Gross and Net Real Power Capability

- The Regional Reliability Organization shall establish and maintain procedures to address verification of generator gross and net Real Power capability.
- The Regional Reliability Organization shall establish periodicity and schedule of model and data verification and reporting.
- The Generator Owner shall have evidence it provided verified information of its generator gross and net Real Power capability, consistent with that Regional Reliability Organization's procedures.

MOD-025-1: Verification of Generator Gross and Net Reactive Power Capability

- The Regional Reliability Organization shall establish and maintain procedures to address verification of generator gross and net Reactive Power capability.
- The Regional Reliability Organization shall establish periodicity and schedule of model and data verification and reporting.
- The Generator Owner shall have evidence it provided verified information of its generator gross and net Reactive Power capability, consistent with that Regional Reliability Organization's procedures.

MOD-025-2: Verification and Data Reporting of Generator Real and Reactive Power Capability and Synchronous Condenser Reactive Power Capability.

- Applicable to Individual generating unit greater than 20 MVA, Synchronous condenser greater than 20 MVA and Generating plant/Facility greater than 75 MVA.
- Where Regulatory Approval is required: Within two years of the regulatory approval, each Generator Owner and Transmission Owner shall have verified at least 40 percent of its applicable Facilities. Within 3rd, 4th and 5th the percentage of verification should reach 60 %,*80 % and 100 %.
- Where Regulatory Approval is not required: Within two years of the Board of Trustees approval, each Generator Owner and Transmission Owner shall have verified at least 40 percent of its applicable Facilities. Within 3rd, 4th and 5th the percentage of verification should reach 60 %,*80 % and 100 %.
- Each Generator Owner shall provide its Transmission Planner with verification of the Real and Reactive Power capability

MOD-026-1: Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions

- Applicable to following Generator :

Interconnection	Individual generating unit	Individual generating plant consisting of multiple generating units with total generation
Eastern	100 MVA	100 MVA
Western	75 MVA	75 MVA
ERCOT	50 MVA	75 MVA

- Each Transmission Planner shall provide following requested information to the Generator Owner:
    1. Instructions on how to obtain the list of excitation control system or plant volt/var control function models that are acceptable to the Transmission Planner for use in dynamic simulation.
    2. Instructions on how to obtain the dynamic excitation control system or plant volt/var control function model library block diagrams and/or data sheets for models that are acceptable to the Transmission Planner.
    3. Model data for any of the Generator Owner's existing applicable unit specific excitation control system or plant volt/var control function contained in the Transmission Planner's dynamic database from the current (in-use) models, including generator MVA base.
- Each Generator Owner shall provide for each applicable unit, a verified generator excitation control system or plant volt/var control function model, including documentation and specified data to its Transmission Planner in accordance with the periodicity as specified in MOD-026.
- Each applicable unit's model shall be verified by the Generator Owner using one or more models acceptable to the Transmission Planner. Verification for individual units less than 20 MVA (gross nameplate rating) in a generating plant may be performed using either individual unit or aggregate unit model(s), or both.
- Each Generator Owner shall provide revised model data or plans to perform model verification for an applicable unit to its Transmission Planner within 180 calendar days of making changes to the excitation control system or plant volt/var control function that alter the equipment response characteristic.

MOD-027-1: Verification of Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions

1. Applicable to Unit as applicable in MOD-026-1
2. Each Transmission Planner shall provide following requested information to the Generator Owner:
    1. Instructions on how to obtain the list of turbine/governor and load control or active power/frequency control system models that are acceptable to the Transmission Planner for use in dynamic simulation.
    2. Instructions on how to obtain the dynamic turbine/governor and load control or active power/frequency control function model library block diagrams and/or data sheets for models that are acceptable to the Transmission Planner.
    3. Model data for any of the Generator Owner's existing applicable unit specific turbine/governor and load control or active power/frequency control system contained in the Transmission Planner's dynamic database from the current (in-use) models, including generator MVA base.
3. Each Generator Owner shall provide, for each applicable unit, a verified turbine/governor and load control or active power/frequency control model, including documentation and specified data to its Transmission Planner in accordance with the periodicity specified in MOD-027.
4. Each applicable unit's model shall be verified by the Generator Owner using one or more models acceptable to the Transmission Planner. Verification for individual units rated less than 20 MVA (gross nameplate rating) in a generating plant may be performed using either individual unit or aggregate unit model(s) or both.

MOD-033-1: Steady-State and Dynamic System Model Validation

- This standard is for establishing consistent validation requirements to facilitate the collection of accurate data and building of planning models to analyse the reliability of the interconnected transmission system.
- The Reliability Standard requires Planning Coordinators to implement a documented data validation process for power flow and dynamics. For the dynamics validation, the target of validation is those events that the Planning Coordinator determines are dynamic local events. A dynamic local event could include such things as closing a transmission line near a generating plant. A dynamic local event is a disturbance on the power system that produces some measurable transient response, such as oscillations. It could involve one small area of the system or a generating plant oscillating against the rest of the grid. The rest of the grid should not have a significant effect. Oscillations involving large areas of the grid are not local

events. However, a dynamic local e vent could also be a subset of a larger disturbance involving large areas of the grid.

- Each Planning Coordinator shall implement a documented data validation process that includes the following attributes:
    1. Comparison of the performance of the Planning Coordinator's portion of the existing system in a planning power flow model to actual system behaviour, represented by a state estimator case or other Real-time data sources, at least once every 24 calendar months through simulation;
    2. Comparison of the performance of the Planning Coordinator's portion of the existing system in a planning dynamic model to actual system response, through simulation of a dynamic local event, at least once every 24 calendar months (use a dynamic local event that occurs within 24 calendar months of the last dynamic local event used in comparison, and complete each comparison within 24 calendar months of the dynamic local event). If no dynamic local event occurs within the 24 calendar months, use the next dynamic local event that occurs;
    3. Guidelines the Planning Coordinator will use to determine unacceptable differences in performance under 1 and 2.
    4. Guidelines to resolve the unacceptable differences in performance identified under 3.

4.2.2 WECC

WECC Generating Unit Model Validation Policy

- This policy statement applies to generating facilities connected to the Western Electricity Coordinating Council (WECC) transmission grid at 60 kV or higher voltage (both new and existing, synchronous and non-synchronous) with single unit capacity of 10 MVA and larger, or facilities with aggregate capacity of 20 MVA and larger. The Generator Owner shall review, verify and update the Generating Facility data when any of the following conditions occur:
    1. No later than 180 days after the new Generating Facility is released for Commercial Operation.
    2. No later than 180 days after an existing generating unit re-starts Commercial Operation with modified equipment, control settings, or software that influences the behaviour of the plant with respect to the grid
    3. At least once every five years.
- The Generator Owner shall test the generating unit and validate its model data. The Generator Owner shall test the generating unit and validate its model data.

- The Generator Owner shall perform model data validation for all units, and provide a report to its Transmission Planner at least once every five years. Schedule of model validation shall be coordinated between the Generator Owner, Transmission Planner and Transmission Operator.

4.2.3 Manitoba Hydro

Transmission System Interconnection Requirements: Modelling Data and Special Tests

- The Generator shall provide preliminary modelling data for the generator and associated equipment for Interconnection Studies and final as-built modelling data following commissioning of the Generator Facility
- The Generator shall determine and document actual generator unit capability, reactive power limits, control settings and response times of generation equipment by field verification and testing to validate generator models and data provided to MH. The test procedures used to validate the response of the generator units shall follow the “MRO Generator Testing Requirements”
- The Generator shall provide detailed models for INTERCONNECTION STUDIES. If the models are proprietary, MH will sign a non-disclosure agreement.
- The Generator shall provide non-proprietary models in standard IEEE format. These models may be released to external regional organizations such as the MRO, MISO, etc. for joint regional studies.
- All models shall be in a format, which can be used by PSS/E and shall be maintained by the Generator. The Generator shall be responsible to revalidate all modelling data from time to time as requested by MH or as required by NERC.

4.2.4 PJM

PJM Region Transmission Planning Process

The guidelines for dynamics data submittal will be as per the Multiregional Modeling Working Group (MMWG) Procedure, which prescribes various test to be done for model validation.

4.2.5 Reliability First

Dynamic Model Standardization Process

- For in-service units, and until NERC standards on dynamic model validation are approved; applicable Registered Entities within Reliability First may submit modelling data supplied by equipment manufacturers with due consideration of excitation, PSS and governor control settings determined during unit commissioning tests. If actual test data is available, that information should be supplied in place of manufacturers' data.

- For proposed units, generator, exciter, turbine/governor, and PSS data submitted using the manufacturers' best estimate modelling parameters. As more refined data becomes available, it should be provided to Reliability First and the appropriate TO. Once the unit is commissioned, actual in-service data should be supplied to Reliability First and the appropriate TO.

4.2.6 SERC

System Modeling Data Requirements

- **Validation of Generator Excitation Systems:** SERC entities shall validate the excitation system model parameters of their generating units which are rated 75 MVA and above and are directly connected to the bulk electric system (BES). Validation for generating units less than 75 MVA will be required if requested by the Transmission Planner and if a technical justification for the need is provided by the Transmission Planner.
- **Validation of Power System Stabilizers:** SERC entities shall validate the power system stabilizer model parameters of their generating units. This section applies only to power system stabilizers that have been tuned and placed into service. The Standard Model will normally be validated during a major scheduled outage. The PSS simulation model will be updated when setting changes are implemented.

4.2.7 Alberta Electric System Operator (AESO)

Requirements for Model Validation Reporting for Generators and Generator Control Systems: The document specifies the test procedure criteria for the generator upon energisation and regular retest after every five years. The model validated should consist of model as provided by the manufacturer, A standard PSS/E model, run with quarter-cycle time step and a standard PSLF model, run with a quarter-cycle time step. These models should be simulated and compared with the test response to give the best fit.

4.2.8 Australia

National Electricity Rules

National Electricity Rules (the Rules) requires Generators to provide Network Service Providers (NSP) and AEMO with a range of data relating to their generating units, control systems and protection systems, sufficient to model the plant and assess its steady state and dynamic performance**.**

- Registered system planning data is the class of data, which will be included in the connection agreement signed by both parties. It consists of the preliminary system planning data. Registered Data consists of data validated and agreed between the Network Service Provider and the Registered Participant, such data being:

a. Prior to actual connection and provision of access, data derived from manufacturers' data, detailed design calculations, works or site tests etc. (R1); and
b. After connection, data derived from on-system testing (R2).

AEMO: Turbine Governor Testing and Model Validation Guideline

- This document is developed to provide Generators with test guidelines suitable for demonstrating compliance with agreed performance standards, as well as deriving validated turbine-governor model data. It is the responsibility of the Generator to ensure that test plans are adequate to derive all the data appropriate for compliance assessment and modelling of various systems used in their installation.
- All turbine and governor models are required to meet the functional and accuracy requirements defined in AEMO's Generating System Model Guidelines. Deviation beyond the model accuracy requirements may be permitted in specific circumstances as agreed between AEMO, the relevant NSP and the generator. The model must accurately represent the performance of the generating unit for all possible operating conditions except for situations where the generator is offline, i.e.: connection point circuit breaker is open. It must therefore respond accurately when compared to the actual generating unit response when simulating a recorded network disturbance or test.
- For all new generators have to provide these details within 3 months of their commissioning tests.
- For other generators, the model to be updated if generators thinks the data are not accurate or incomplete in nature or based on requirement from the AEMO or NSP.
- A set of models used in PSS/E has been defined for governor and turbines.

4.2.9 Ireland (EIRGRID)

EIRGrid Code

- **PC.6.6.1: System planning Data:** The Planning Code requires that, as soon as is practical, and not later than a date which is the earlier of 18 months prior to the scheduled Operational Date or six months after the signing of the Connection Agreement, unless otherwise directed by the CER, all data requirements as stated in the Appendix to the Planning Code, not previously requested by the TSO and supplied by the User, will be submitted by the User to the TSO. This will include confirming any estimated values assumed for planning purposes or, where practical, replacing them by validated actual values and by updated estimates for the future and by updating forecasts for Forecast Data items such as Demand. As more accurate data becomes available, due to completion of detailed design, test measurements/results or any other sources, this information will be submitted by the User to the TSO as soon as practicable and not later than the Operational Date.

- **PC.A4.10.1.3 Validation of Model:** All models provided to the TSO for use in dynamic simulations must be validated. The TSO must be satisfied that the behaviour shown by the model under simulated conditions is representative of the behaviour of the real equipment under equivalent conditions.
- The EIRGRID has various provisions for Wind Generators for model validation.

4.2.10 ENTSOE

Network Code: Common Provisions on Compliance Simulations

- The Power Generating Facility Owner shall provide simulation results relevant to each and any individual Power Generating Module within the Power Generating Facility in a report form in order to demonstrate the fulfilment of the requirements of this Network Code. The Power Generating Facility Owner shall produce and provide a validated simulation model for a Power Generating Module.
- The Relevant Network Operator shall have the right to check the compliance of a Power Generating Module with the requirements of this Network Code by carrying out its own Compliance Simulations based on the provided simulation reports, simulation models, and compliance test measurements.
- The Relevant Network Operator shall provide to the Power Generating Facility Owner the technical data and the simulation model of the Network, in the extent necessary for carrying out the requested simulations according to details given in the Network Code.

4.2.11 National Grid UK

- Simulation studies and site tests are required to provide evidence that the Generators plant and apparatus comply with the provisions of the Grid Code.
- Model Validation: The results recorded during the compliance tests may be used to validate the model of the excitation control system and the frequency control system. The tests above may have proved that the generator and its control systems are compliant but the recorded behaviour tests may be different from the behaviour predicted by the simulation studies using the provided models. The differences may be due to the following reasons. :
    1. The simulation conditions are different from the test conditions.
    2. The model supplied may be not accurate.

Following successful compliance tests the Generator should validate the performance of the submitted model by providing overlays of recorded tests with simulations replicating as far as reasonably practical the same conditions. Simulation of the test under the test conditions should be carried out and the simulation results should be then compared with the test results. If the results are identical or matched very well then the submitted model has been validated and accepted as the accurate model of the plant. If the results are different then the Generator, or the Generators agent, i.e. consultant or equipment manufacturer, should resubmit a modified model. This process will be repeated until there is close agreement with the test results and simulation results.

4.2.12 Kenya

Electricity Grid Code

S3.5.2: Utility have to submit two sets of registered data : Registered Data consists of data validated and updated prior to actual connection provision of access from manufacturers' data, detailed design calculations, works or site tests etc. (R1); and data derived from on-system testing after connection(R2). All of the data will, from this stage, be categorised and referred to as Registered Data; but for convenience the schedules omit placing a higher ranked Code next to items which are expected to already be valid at an earlier stage.

S3.5.3: Data will be subject to review at reasonable intervals to ensure its continued accuracy and relevance. The network service providers shall initiate this review. A Code Participant may change any data item at a time other than when that item would normally be reviewed or updated by submission to the network service provider of the revised data, together with authentication documents, e.g. test reports.

4.3 Summary of the Model Validation Criteria

Based on the previous section on the worldwide adopted standard and regulation for model validation, it can be crafted out that the criteria helps from planning regime to operational regime. The global practice on model validation can be summarised as following:

- In most of the large and small Grid across the world, the model validation made mandatory in order to have a beater planning and operation of the electrical grid.
- The model validation was found to be necessary as the actual system behaviour and model system behaviour has a large gap during the operational regime based on the data submitted.
- There should be a regulation for the Model validation duly approved by the regulatory commission or a part of Electricity Policy/act.
- Based on these regulations, Transmission planner will ask the details for the validated model from the Generator owner for governor/turbine/exciter/stabiliser.

- This should include generator of 100 MVA and above for larger grid and more than 2.5 MVA for smaller grid.
- Transmission Planner will ask the validated model for FACTS devices from the Transmission Owner.
- Transmission planner will also provide a set of models in which the generator/transmission owner should provide the details in order to validate the simulated and test result.
- The timeline for providing complete details should be within 5 years for complete system.
- Validation test should be performed for each system component described above within 5 years.
- If there is a change in the actual system or any change in model being done by the generator/transmission owner, then the changes in the model should be informed to transmission planner within 6 months.
- Transmission planners shall also validate their portion model with the steady and dynamic response observed in actual system.
- After validation the data will be shared with reliability coordinator and system operator for operational purpose.
- All transmission planning and operation should be performed based on the validated data for best optimum results.

4.4 Requirement of Model Validation and India

Indian Power system is at its peak in terms of development taken in the Generation, Transmission, and Distribution. The system is changing year by year with the addition of large generation, long EHV lines, HVDC links, distribution links and adoption of new technologies. However, there have been several challenges that are being experienced by system operator which were not observable in the planning regime. Such includes the low frequency oscillation, sub-synchronous torsional interaction, sub-synchronous oscillation etc. It has been observed on many occasions that the planned system model behaviour and the actual system response have varied widely. The planning and operational model validation is now a challenging task for system planner, reliability coordinator, and operators. At present, there is no standard for model validation in Indian power system. During the last grid disturbance, the response of the system was different on two consecutive days which as of yet could not have been established based on simulation model. This drives the need of model validation in Indian power system. The model validation aspect itself was not directly a part of the Enquiry committee report, however, there were recommendations that indirectly reflect to model validation at field level. These can be summarised as following:

- Ensuring primary frequency response from generators

- Revising Total Transfer Capability (TTC) based on change in system conditions.
- Optimum utilization of available assets
- Need of Dynamic Security Assessment and review of State Estimation.
- There are enormous amount of benefits of the model validation in power system out of which some can be enumerated as following:
- Realistic models are needed for ensuring reliable and economic power system operation.
- The database of the dynamic models used for modelling and the actual equipment in filed validation.
- Correct representation of generator real, reactive power capabilities, and the limiting factors involved.
- Finding the root cause of low frequency oscillation in the grid and remedial measures.
- Voltage stability enhancement in the grid.
- Improved generator control tuning in a power system having more than one units for better response and mitigation of local issues.
- Better Power system damping with the tuning of PSS.
- Better frequency response through governor testing and their limitation.
- Many more for the benefit of complete power system fraternity in order of to “Know your system” approach.

Thus, the need for model validation in large power system like India which is growing at a fast pace is essential for better planning and operation of the grid in a safe, reliable and secure manner.

4.5 Model Validation Approach for Indian Power System

Before designing our way for the approach to take for model validation, the below two quotes are very relevant to the power system in terms of how each component affect other in the synchronised grid.

"Coming together is a beginning. Keeping together is progress. Working together is success." Henry Ford.

“Swing is extreme coordination. It's a maintaining balance, equilibrium. It's about executing very difficult rhythms with a panache and a feeling in the context of very strict time. So, everything about the swing is about some guideline and some grid and the elegant way that you negotiate your way through that grid” Wynton Marsalis.

So, in order to have a good model, validation has to be performed in phase wise manner for all the elements as each of them has impact on the other when run in synchronism. To achieve this following step has to be ensured:

- In order to achieve this, the first requirement is the regulation which makes it mandatory for equipment owner to perform model validation. This has to be included in some form either in the CEA Grid standard or Indian electricity grid code.
- Second is the procedure development for the model validation by the planning agency with system operators.
- The generator of more than 100 MW in thermal and 10 MW in Hydro should be first considered for validation. The validated model should also be tested on simulation software with the measured data in order to verify the model for making it more realistic in nature.

In the next section, the use case of the exercise on reactive power model validation has been described in details. This will help in understanding the requirement of model validation for planning and operational purpose. How the validated model help the generator as well as grid operator in operating the grid in reliable way.

5 Reactive Power Capability Validation in Southern Regional Grid

5.1 Introduction

The reactive power absorption or injection by generators is important in view of maintaining the voltage profile in the grid in order to achieve the voltage stability. Further, it also helps in keeping the equipment away from the damages due to operation beyond specified voltage limit resulting in voltage stress. Each generator is unique and its capability curve varies however the limits of generator capability curve remains the same. So, it is necessary to utilize the available reactive power capability of generators to its maximum without violating any of the limits at a rated active power output.

Generator reactive power capability for any generator is related to the thermal limitations of the generator itself. It is the amount of reactive power that is available at the terminals of the generator if system voltages are such that full reactive power support is demanded. The major factors impacting the electrical generator's reactive power capability are depicted on the generator's reactive power capability curve (also known as D-curve) as shown in figure 5.1. These factors are:

1. MVA rating of the generator (Limitation from stator/armature thermal heating)
2. Rotor main field winding thermal or current limitations
3. Stator end core thermal limitations
4. Actual generator MW output versus the MW rating of the generator at rated power factor.
5. Coolant temperatures

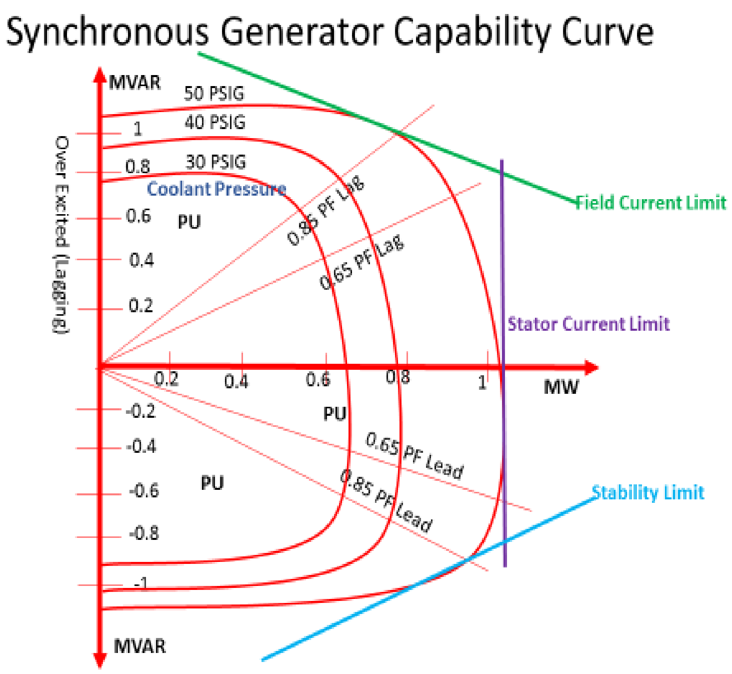

Figure 5.1: Synchronous Generator Capability Curve

The generator capability curve is a 3D diagram as at each point of time some limitation may get hit. Such type of representation is shown in figure 5.2. It shows the envelope of real and reactive power at each power factor.

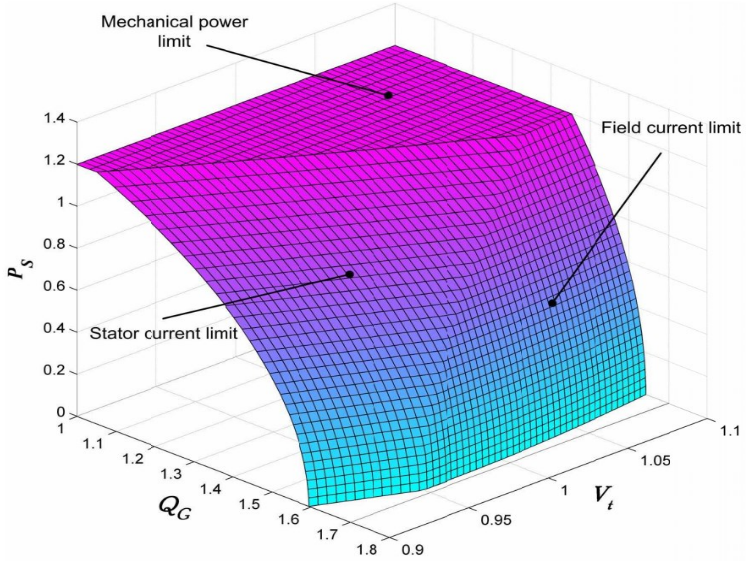

Figure 5.2: Synchronous Generator Capability Curve (3D)

However, in the generator manufacturer capability curve, the various limitations arising other than from generator design are only quantified. Such as impact of transmission voltage at generator bus, auxiliary equipment voltage, Generator bus fault level are not reflected. So, it is important to know that the Generator Reactive Power Capability curve only represents the capability of the electrical generator itself i.e. various limitation arising out of its manufacturing and material used for a rated design capacity. It does not take into account:

1. The design of the auxiliary power system and its coordination with the generator terminal voltage;
2. The Generator transformer electrical characteristics;
3. The strength of the transmission system to which the generator is connected (Fault MVA)
4. The transmission operating voltage and coordination with the GT tap setting;
5. Generator protection system settings.

These five factors will also affect the Generator reactive power capability. The distinction between the "Generator reactive power capability" and the "Generating Unit reactive power capability" must be understood, evaluated and reported so the generating unit can be modelled correctly in Transmission Operations and Planning studies. Such factors also need accessing to get a better picture for any generating units and its capability when connected to the grid. These criteria would only come out with testing of generators when connected to the grid at any point in time.

Following are the various limiter which restricts the Generator Performance:

1. Field Over and Under excitation limiter
2. Inverter over current limit
3. Generator limits set for reactive power capabilities. (Stator/Rotor core temperature limit,
4. Volts per Hertz (V/Hz) limiter
5. Stator over-voltage protection system
6. Generator and transformer Volts per Hertz capability (Over flux, Maximum generator terminal voltage, Generator Tap coordination)
7. Time vs. field current or time vs. stator current.
8. Load angle limit
9. Turbine/Generator/Excitation Vibration
10. Generator Hydrogen Cooling

There may be other factors apart from the above mentioned which may also result in limiting the reactive capability testing of generators. So, the capability curve submitted by the generators needs to have two kinds of check i.e. one is the verification of setting of various limiters as these may be set at lower value and other is to check the actual limits when the testing is being done in order to calculate the revised reactive capability curve under various grid condition (Peak and off peak). Such kind of details can only come from validation of generator reactive capability curve. In the next section, the experience of Southern Regional grid operators has been shared in the area of generator reactive capability testing to determine the various limits for the existing generator. This has helped both the generator as well as System operator in accessing the limits and gaining more confidence in operating the unit under various regions of capability curve for improving system voltage profile.

5.2 Southern Region Generator Reactive Capability testing

Southern grid experiences the simultaneous existence of high voltage and Low Voltage pockets while the desirable for secured grid operation is to have good voltage profile near to rated system voltage in the entire SR grid. Voltage being local phenomena, the issue can be addressed by putting all Reactive sinks / Sources into service to the required level within the permissible limits.

In addition to proper demand side management & switching operation of reactors, optimization of MVAR absorption / Injection by the generators plays a vital role in maintaining the voltage profile within the IEGC mandated range. Although the Manufacturer supplied capability curves give a fair idea on the extent to which the generators MVAR capability can be utilized, the influence of operating parameters as well as operator is significant in deciding absorption / injection of MVAR quantum in real time grid operation. To facilitate the operator's real time decision making process effectively, an endeavour is made to ascertain the MVAR absorption / injection of each generating unit in SR within the safe practical limits. Hence, Capability testing gains importance & series of testing has been planned in Southern Region. Accordingly the testing was carried out at the following generating during November 2013 to October 2015.

Sl.No.	Station	State	Test conducted on
1.	Srisailam Right Bank	Andhra Pradesh	November 2013
2.	Srisailam Left Bank	Telangana	November 2013
3.	Vijaywada TPS	Andhra Pradesh	November 2013
4	Raichur TPS	Karnataka	January 2014
5	Nagjhari	Karnataka	January 2014
6	Kadra	Karnataka	January 2014
7	Kodasalli	Karnataka	January 2014
8	NTPC Simhadri	NTPC	February 2014
9	SEPL & MEPL	IPP	August 2014
10	Kothagudem TPS	Telangana	October 2014
11	Mettur TPS	Tamilnadu	October 2014
12	Rayalseema TPS	Andhra Pradesh	November 2014
13	Ramagundam STPS	NTPC	June 2015
14	NTECL Vallur	NTPC and Tamilnadu	July 2015
15	North Chennai TPS	Tamilnadu	July 2015
16	SDSTPS	Andhra Pradesh	July 2015
17	Idukki HEP	Kerala	September 2015
18	Sharavathy HEP	Karnataka	October 2015

5.2.1 Experience of testing and observation during the reactive power capability model validation

Station	Unit Capacity	Unit No	Possible Injection (MVAR)	MVAR injected during testing	Observations	Possible Absorption (MVAR)	MVAR absorbed during testing	Observations
Srisailam LBPH	150	1	High Voltage Zones, Lagging Side Test Could Not Conducted			-60	-60	1. Condenser mode absorption limit is 110 MVAR; generator limiting to 60 MVAR 2. No limiter operated
Srisailam RBPH	110	1	High Voltage Zones, Lagging Side Test Could Not Conducted			-30	-30	1.Capability limit touched 2.Test was successful
VTPS	500	7	High Voltage Zones, Lagging Side Test Could Not Conducted			-180	-156	Load angle limiter hit (85deg)
VTPS	210	3	High Voltage Zones, Lagging Side Test Could Not Conducted			-90	-47	Generator terminal Voltage hit LV side(15kV)
VTPS	210	5	High Voltage Zones, Lagging Side Test Could Not Conducted			-90	-66	Generator terminal Voltage limit was hit at LV side
RTPS	210	3	High Voltage Zones, Lagging Side Test Could Not Conducted			-12	-3	UAT voltage limit was limit
RTPS	210	7	High Voltage Zones, Lagging Side Test Could Not Conducted			-102	-44	LV voltage of 15kV Limit was hit
Nagjhari	135	3	High Voltage Zones, Lagging Side Test Could Not Conducted			-70	-33	Full capacity testing was not done due to up gradation and OEM yet to confirm
Nagjhari	135	5	High Voltage Zones, Lagging Side Test Could Not Conducted			-70	-61.4	Full capacity testing was not done due to up gradation and OEM yet to confirm

Station	Unit Capacity	Unit No	Possible Injection (MVAR)	MVAR injected during testing	Observations	Possible Absorption (MVAR)	MVAR absorbed during testing	Observations
Kadra	50	1	High Voltage Zones, Lagging Side Test Could Not Conducted			-22	-18	Stator current limiter hit
Kodasalli	40	1	High Voltage Zones, Lagging Side Test Could Not Conducted			-17.8	-11.6	When LV side max was hit
Kodasalli	40	1	High Voltage Zones, Lagging Side Test Could Not Conducted			-17.8	-15.6	Vref minimum was hit
Simhadri	500	1	280	169	Generator terminal voltage touched its maximum limit & System voltage High	-180	-150	Load angle limiter operated
	500	3	280	-	Generator terminal voltage touched its maximum limit & System voltage High	-180	-108	Load angle limiter operated(79 deg)
MEPL	150	2	96	91	Capability curve touched	-45	-45.5	1. Under Excitation limit hit 2. Operating at higher LV reference leading to lesser absorption
SEPL	150	1	105	103.5	Capability curve touched	-80	-65.6	1. Hot air temp alarm hit 2. Operating at higher LV voltage 3. AVR in power factor mode
KTPS	250	9	130	15	Terminal Voltage limit reached	-80	-52	Calibration/tuning of parameters not done
KTPS	500	11	300	29	Terminal Voltage limit reached	-180	-34	As per MVAR capability curve
MTPS	210	1	130	120.5	Vf = 310 V reached	130/-20	-20	As per MVAR capability curve
MTPS	210	4	130	80	AVR Auto reached Max.	130/-20	-20	As per MVAR capability curve

Station	Unit Capacity	Unit No	Possible Injection (MVAR)	MVAR injected during testing	Observations	Possible Absorption (MVAR)	MVAR absorbed during testing	Observations
RTPP	210	1	130	91.8	Terminal Voltage limit reached	-90	-68	Low excitation alarm was hit
RTPP	210	4	130	102.2	Terminal Voltage limit reached	-90	-51	Low excitation alarm was hit
RTPP	210	5	130	100	Terminal Voltage limit reached	-90	-64.2*	Not completed due to coal shortage problem
RSTPS	200	2	-	38	Auxiliary Bus Voltage High	-60	-60	Capability curve touched
RSTPS	500	4	-	-	Voltage was more than 415 kV no Significant injection observed	-150	-152	Capability curve touched
RSTPS	500	7	-	-		-150	-149	Capability curve touched
NTECL Vallur	500	1	320	290	Field current limiter operated at 3490 A	-180	-116	Load angle limiter acted at 79.5
NTECL Vallur	500	3	320	228	Vref Limiter acted	-180	-123.5	Load angle limiter acted at 82.4 deg
NCTPS STI	210	1	135	142	Capability curve touched	-10	-25	Capability curve touched
NCTPS STI	210	3	135	132	Capability curve touched	-10	-38	Capability curve touched
NCTPS STII	600	1	360	326	Field current limiter acted at this point	-280	-102	Load angle limiter acted at 86 deg

Station	Unit Capacity	Unit No	Possible Injection (MVAR)	MVAR injected during testing	Observations	Possible Absorption (MVAR)	MVAR absorbed during testing	Observations
SDS TPS	800	1	600	271	V/f limiter Acted (Setting: 105%)	-480	-107	Minimum excitation Limit reached.
Sharavathy	103.5	1	45	22.5	field current limit touched	-46	-41	Stator current limit
Sharavathy	103.5	7	50	30	field voltage max limit touched	-49	-44	Stator current limit
Sharavathy	103.5	10	50	31	field voltage max limit touched	-49	-45	Stator current limit

5.2.2 Observations

So, after several number of reactive capability testing, the reason for limits in reactive power absorption/injection has been identified. The limits which have been observed during the leading side testing are as following:

1. Under Excitation Limiter
2. Load Angle Limiter
3. Low Auxiliary Bus Voltage Limit(Lower Side)
4. Stator Current Limit

While when t test were carried out for the lagging side, following limits has been observed:

1. Field voltage limit
2. Field Current Limit
3. Generator Terminal Voltage Limit(Higher Side)
4. Stator Current Limit
5. Low Auxiliary Bus Voltage Limit(Higher Side)

In Southern region most of the locations, where test was conducted, are High voltage zones. So the testing on lagging side could not be conducted up to capability limit.

5.2.3 Recommendations of testing committee:

1. There is a difference in parameters displayed in the meters located in control room & meters at remote end, Committee recommended for calibration of all the meters as per standard Industrial practice.
2. All the AVRs should be kept in voltage control mode wherever they are set in power factor control mode.
3. All the taps of a particular station has to be set as per recommendations of SRLDC/SRPC and all the taps are to be set to the same voltage level so as to avoid circulating currents.
4. Tuning of AVR setting, Load limiter setting etc., needs to be done to ensure performance as per the requirement.

5.2.4 Benefits derived from testing:

1. Before the commencement of testing the operators were limiting the MVAR absorption by generators, though the system voltages are high & huge gap between the actual absorption & absorption as per as per capability curve. This testing built confidence in the operators, now to the maximum extent possible the generators are absorbing MVAR.

2. The MVAR absorption/Injection by the generators in Southern region is continuously monitored and any shortfall in the performance as per system requirement has been taken up in various forums like OCC and SRPC.
3. The operators at RLDC will be having fair idea to what extent they can utilize the capability in case of any contingency.
4. For short term voltage problems (due to delay in transmission lines etc...) utilizing the MVAR capability of the generator is viable option instead of going for reactor/capacitors which require huge investment.

5.3 Conclusion

The reactive power testing activity is a good exercise that has to be done in order to determine the actual capability of generator reactive power absorption or injection according to the grid condition. This helps generator owner as well as the power system operator to vary the absorption/injection of reactive power as per the new modified curve without affecting the generator performance and its life.

The Ramakrishna committee report on “Task Force on Power System Analysis under Contingencies” also expressed that such testing are important. The extract from the report is reproduced as “*Participation of generations in reactive power management towards controlling voltage profile is a critical area requiring attention. Generator reactive capability is required to maintain proper system voltage levels, provide appropriate dynamic reserves and assure service reliability. However, it was generally observed that generators shy away from providing full support taking shelter under pretext of operating conditions limiting their capabilities. In this context, there is a need to validate reactive capabilities of generators in a uniform manner to arrive at realistically attainable values which should be used in planning and operation of grid.”*

In view of the above and requirement of reactive power absorption/injection as per regulation of Grid code and CEA standard, the same should be carried out in all the generating units pan India. Such type of testing should be mandatory for all generating station as observed in various grid codes across the world.

Thus the use case has shown how the model validation process in one or other way helps planner and system operator to know better about the available resources in the system. This will certainly help in simulation of the generators and finding the desired reactive power requirement in the system according the actual system behaviour.

6 Conclusion and Way Forward

The present report has presented with a good overview of the power system modelling and its various aspects in India. This report has shown the various challenges being faced by Indian system operator due to lack of standard and regulation in terms of power system model, its verification and validation on periodic interval. It is a way forward in the area of the model submission, model verification and model validation criteria in Indian grid. It is prepared in order to provide a feedback to planners and regulators on the challenges being faced by system operators in terms of low frequency oscillation, dynamic response, variation between actual system repose and simulation based on the available model and why it is essential to have regulatory provisions for model submission, verification and validation. The present standard/regulation in India along with global outlook has been provided in these area to find the various gaps.

Further, this report in combination with “Report on Low frequency oscillation in Indian Power system” has also set the path to act as a guide for utilization of available measurements from PMUs for model validation process. With the installation of more number of PMUs in Indian grid, the next step is to utilize the same for fine tuning of generator model which would be a great help in order to have model response to be near to the actual response. Apart from these utilization of Synchrophasor data has to be done in order to improve state estimation, offline model, line parameter validation etc. While on the model side, actual model validation of generating unit as a demo has to be taken as an initiative to provide inputs for its effectiveness. Overall lot of other developments in the area has to done in order to have good model for power system simulation which will represent the actual system.

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