Making Grid Future Ready for RE Generation, Indian Perspective

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Blackouts or brownouts can happen anytime without warning. Some of the largest and most stable grid companies in the world have suffered losses of hundreds of, millions of dollars due to disturbances lasting from milliseconds to few seconds. The recent cases of Grid failures in New York area and South American (Brazil), explains the story of unstable operation of grid, resulting in wide spread power failures. With rapid installation of renewable energy and storage, reliable grid operation is further exposed to challenges.

With adoption of renewable energy resources as prominent source of power supply, Indian grid is also encountering challenges in delivering power. Electric utilities and grid operators are assigned to integrate distributed source of energy without compromising on steady flow of the electric power. The Indian model is unique for Distributed Energy Resources (DERs). Renewable energy is categorized at 4 levels (i) Distribution level for Rooftops up to 5MW is dealt by DNOs (ii) 5 to 30MW levels are connected at sub transmission levels and dealt by TSOs (iii) >30MW are connected to HV Transmission levels of STUs (State Transmission utilities) (iv) Ultra mega Solar plants of >500MW are connected to national grid. The Ultra Mega PV plants are being added in small area or region with interstate transmission system being developed at EHV levels. Any interruption is an inconvenience and value of this inconvenience is different for different users. Utilities have started acknowledging the need for change within the commercial distribution prospective of electrical power with merit order dispatches making the system complex.

Earlier days faced most of the variation from demand/load side. Current scenarios have brought variations at supply end as well. Opponents of renewable energy are propagating these inherent natures of variability and instability to prevent integration of renewables with electric grid. On the contrary some countries and regions have presented successful integration of wind and solar, meeting more than 50% of their energy needs through renewables. Denmark and South Australia report solar and wind generation levels of 53 percent and 48 percent, respectively. These high levels of variable generation integration have been achieved with no compromise in power supply or reliability. This can be achieved with better controls. However; when controls come into picture, we are left in hands of load dispatchers. This creates an emergence to re-look existing business models and business perspectives.

Emergence of Renewable energy stems from the need to reduce hazardous environmental impact. India being the signatory of Paris accord, is endeavoured to supplant older fossil-based plants with renewable plants. Today's energy systems demand efficiency, reliability and security. However; integration of renewables into our electric grid makes it not grid convivial currently. The RE generation is required to change from must run to must support grid status in future.

Previous challenges of using renewables in electric power

Renewables are not always efficient, reliable and secure source of energy. Weather conditions hamper the ability to collect this energy. Renewable resources (Sun, wind, rain) do provide energy, but being sporadic in nature they also create challenges for the utilities. In order to incorporate renewable energies into existing infrastructures, utilities and generators must address several primary issues, making system unstable:

Voltage management: Voltage is exclusively important to control and TSOs are looking for the options such as Secondary and Tertiary Voltage Regulators; reactive power compensators like the STATCOM (Static Synchronous Compensator). However, the fact that each piece of PCU is capable of STACOM operation is being ignored. The inverter can control the local bus voltages. The design concept of loading the electrical system to 100% loading during full resource availability and unloading it full during the absence of resource make the wide variability in network voltage controls. STATCOM action should be used for local voltage controls and Capex on Var compensation elements at HV levels should be reduced.

Frequency control: A power system often has inconsistent frequencies when adding renewable energy due to their intermittent nature. Companies are probing for solutions that can regulate frequency variations within a specified range by using a faster controlled response. The RE sources are extremely fast in response due to power electronics based controls and actions. The RE sources can definitely act fast in Ramping down the generation which is undermined at particular moment of time. As a changed philosophy, the Ramp down role can be given to RE generators and Ramp up with conventional sources, as Ramping up may have constraints of resource availability in Renewables.

Controlling output fluctuations: Absorbing excess energy in cases of excessive output fluctuations will help companies maintain a smooth power curve. The smaller grids displayed larger frequency deviations than larger grids. Indian system of approximately 200GW is too large and can absorb fluctuations due to higher grid inertia number. In addition, comparing different regions showed that a larger share of renewable generation resulted in larger frequency deviations. Indian grid with total installed capacity of >300GW and peak demand of >200GW is one of the largest in the world and have high grid inertia number. The planners see this as primary problem till the present target of 165GW renewable is added into the system.

Demand response: This is one of the more commonly known solutions for managing energy, and is increasingly being applied to renewables as well. DR allows for the system to automatically request the users suppress power consumption during peak hours, and can automatically shift any surplus power load to a later time. The ToD tariff and other mechanism are the tools to implement the DR application. But these tools are not very popular in Indian grid except in Industrial zones in few states.

Power system Stability is function of three main elements (i) Rotor angle stability (ii) Frequency Stability (iii) Voltage Stability. The combination of stability in three of the above gives a stable grid operation. The three stabilities have again two components one for very short/small durations and the other for Long durations. The table below describes the brief about the stabilities.

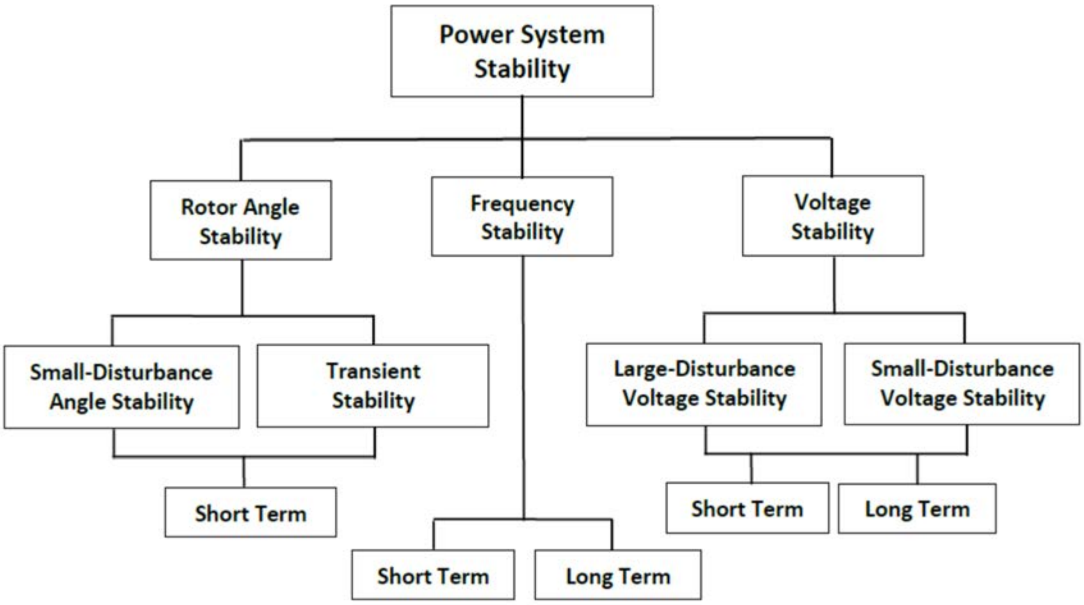


Figure-1: Type of Power System stability

Coping with Limits for Very High Penetrations of Renewable Energy

In last 10 years, the integration of Renewable Energy Sources (RES) on electricity power systems across the world has increased considerably. This development is set to increase even further over the coming decades, and the majority of this increase is expected to be from Inverter based Variable Non-Synchronous Renewable (VNSR) generation. This fluctuating energy will alter the fundamental behaviour of power systems and introduce new challenges. Against the backdrop of these changing inputs, it will be necessary, to ensure the right long term commercial signals for a complementary generation portfolio mix. Existing conventional plant will need to be operated in modes that are likely to increase wear and tear and require greater flexibility. It is expected that VNSR will be required to produce energy and facilitate ancillary services.

Control Capabilities

There are ranges of policies and practices that will need to be employed to manage the input changes on the power system over the next decade. There is a clear consensus that for medium and high level RES additional grid infrastructure will be required. In addition, the techniques and criteria used to determine the network might need to change to identify a more efficient network structure. Increased interconnection can cause issues for neighbouring systems due to performance or non-performance of other utilities. There will be a need for greater information and transparency. Forecast accuracy is considered a key requirement for all penetration levels of VNSR. There is a clear signal that ancillary services will play an increasing role in the secure operation of the future power systems worldwide. Dispatch and ramping capabilities of new and existing conventional plant will need to increase with higher levels of RES.

Proposed Technical Categorization of RE Generators

Category-I: (Very small connected to DNOs) For these RES, technical requirements stipulate they remain in operation in case of frequency deviations in the range of 47.5 - 52 Hz range and voltage deviations in the normal range. Additionally conformity of the inverters for LVRT. The provisions of LVRT are made mandatory for Indian generators in 2016

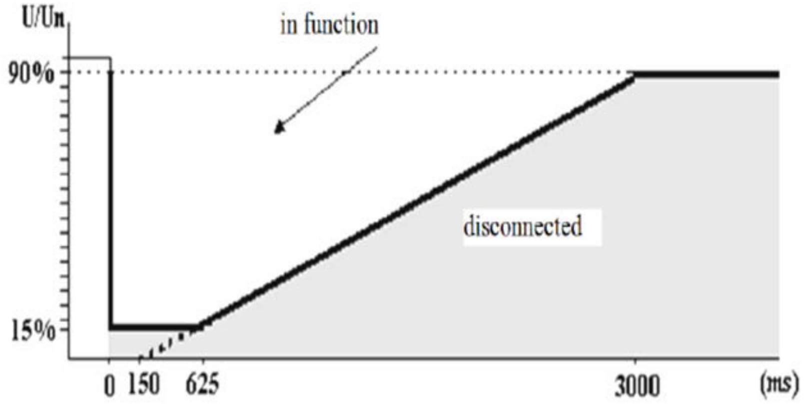
Category II: (Small connected to Medium Voltage Networks of DNOs) The larger RES with an installed power over 5 MW the provision here is the obligation to be integrated at least with active and reactive power real time measurements into the DMS SCADA (Distribution Management System SCADA).

Category III: (Large connected to TSOs) The RES with larger installed power capacity the active and reactive control loops with remote control are required. Active and reactive power integration - SCADA and DMS SCADA - is mandatory.

Category IV: (Very Large connected to Extra high Voltage systems) The forth category includes RES with an installed capacity greater than 10 MW. The requirements include active power frequency dependence and a direct connection to the EMS SCADA which provides active power, reactive power, and voltage measurements and set points for the control loops, even if those PPs are connected to the DSO grid. The communication path must be redundant using at least one fibre optic path.

Actual technical requirements

Robustness is required as low voltage ride through (LVRT) based on figure 2 and shall be demonstrated by records of tests provided by a Central Electricity Authority of India. It is also essential to contribute with reactive current during dips, especially for power plants greater than 10 MW.



Figuer-2: LVRT characteristic

Voltage control at the Control Panel is mandatory for power plants greater than 10 MW. In many cases, the voltage loop control includes the tap changers of the step-up transformers. A proportional integral (PI) voltage control loop (with a limited integral term) is required in order to have a limited control action. The auxiliary devices for reactive power compensation in CP must be included in the control loop. Reactive power compensation in the Control Panel is required for PPs greater than 5 MW in case the energy source (wind/sun) is interrupted. It is mandatory to compensate reactive power as close as possible to zero.

Frequency Response: As per Indian regulations, the solar and wind machines should operate in range of 47.5 Hz to 52Hz. The machine should deliver rated output from 49.5Hz to 50.5Hz. But output regulation is demanded as per frequency response between frequency range from 49.9Hz and 50.05Hz Active power frequency response (the P – f profile shown in figure 3) is now requested by Grid controlling authorities for PPs greater than 10 MW. It is usually a linear function in the active power controller at the PP level. For small PPs, the P-f profile can be activated at the generating module level having P-f profile, but the reconnection for frequencies larger than 50,2 Hz can be allowed at any frequency values following the P – f profile.

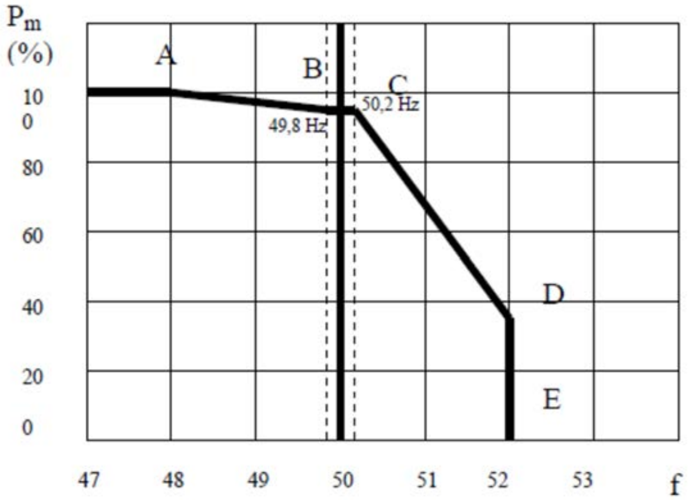


Figure 3: Droop Characteristics

As in India, RES are given the status of Must Run the backing down can be handled by the droop characteristics. The inverter control droop characteristics is in 3-5 steps and is required to be in built in machines. The future inverters should have such capabilities for control actions. Two aspects are important: the provisioning continuous active power reserves (1% of installed power) relative to the available power delivered for frequencies less than 49.8 Hz. The 1% power boost to needs to inject for transient grid support in case of sudden fall in frequency. The SCADA control capability needs to be develop for plants to enable this feature. The future PPAs should have the provisioning of this aspect. Otherwise there can be provisioning of 1% extra generating modules as PPA condition to be used for emergency injection and mechanism and regulations to enable the same needs to be developed. Modules (e.g. 1% of generating modules of the PP) which assure the reserve for the entire power plant.

Reactive power control, we can note differences between a Wind and a PV PP, based on the P-Q capability diagram. For a WPP, the P-Q diagram in the CP is more or less fixed and pre-calculated, while for a PVPP this diagram must take into account the available apparent power versus irradiance. Usually, active power is a priority. Remarks on active power ramps are also available for the reactive power control of a PVPP and a WPP.

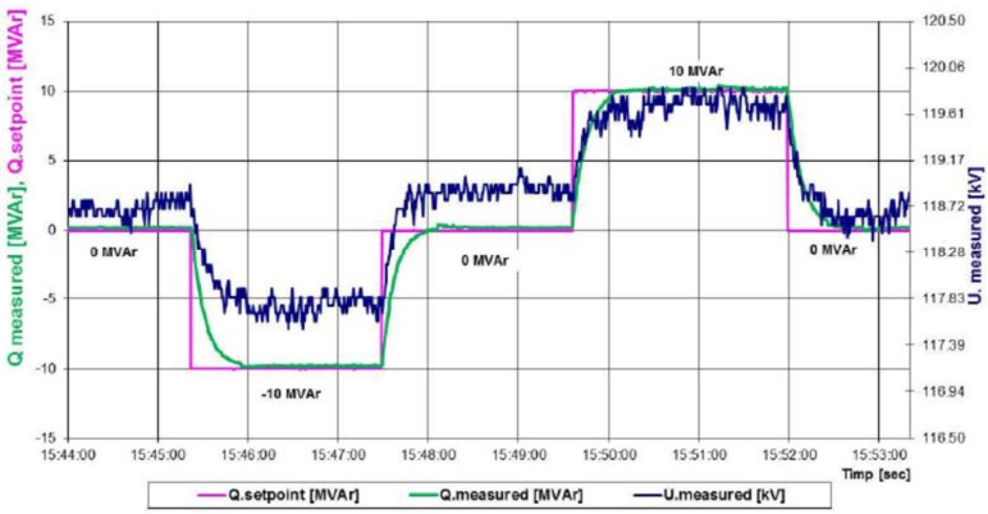


Figure 4: Reactive Power control at 110KV GSS

Voltage control represents the current operation mode for all WPPs/PVPPs greater than 10 MW. The voltage control must be based on a PI algorithm, which permits a continuous reactive power adjustment based on real time PP voltage contribution and the apparent short-circuit power in connection point. Under this condition, the TSO can impose the obligation to implement special measures to avoid reactive power injection into the grid when the PP has stopped by inverters, if they are equipped with @night function. In other cases, it is mandatory to install auxiliary equipment such as shunt reactors or SVC/STATCOM. Theoretically, to avoid a remaining energized cable without compensation, one may install a compensation device in the CP, or - more practically - automatically disconnect the circuit breaker in the grid substation when the PP's circuit breaker trips.
Voltage control record tests are shown in figure 5.

Frequency Response regulation: The proposed regulation demands that any power plant wind or solar above 10MW should response to frequency drift in form of real power response. The response should be similar to drop characteristics from 3 to 6%. The wind and solar generators should respond for both down regulation and up regulation. For small frequency deviation of +/- 0.3Hz wind and solar should response proportional to frequency deviations. For larger deviations in excess of 0.3Hz Wind and solar generators should respond by approximately 10% of AC capacity in 1 sec. based upon the upregulation are expected with BESS or some other means. Generator shall be equipped with the facility for controlling the rate of change of power output at a rate not
more than ± 10% per minute.

The generating stations of aggregate capacity of 500 MW and above shall have the provision to receive the signal from the State Load Dispatch Centre or Regional Load Dispatch Centre, as the case may be, for varying active and reactive power output.

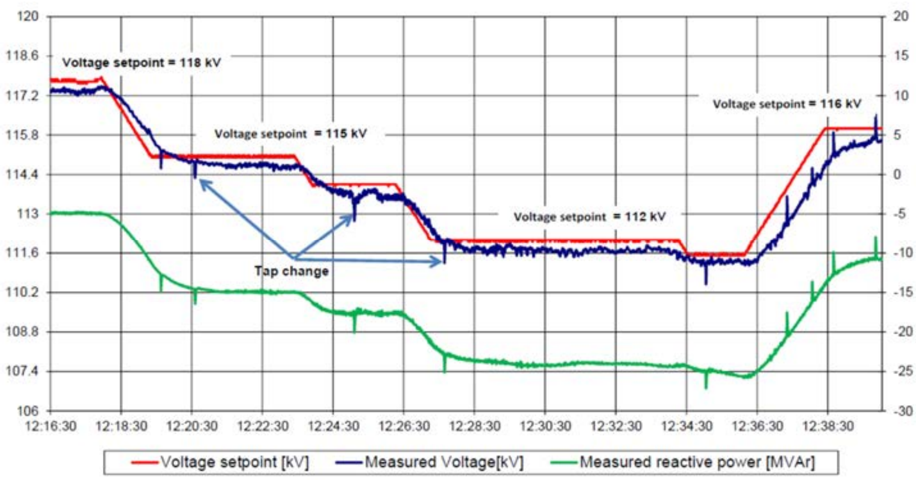


Figure 5: Voltage Control Loop

Future Frequency & Voltage Monitoring

All dispatch able units, including Thermal Power Plants (TPP) greater than 20 MW and Hydroelectric Power Plants (HPP) greater than 10 MW are to be integrated in the EMS SCADA with active/reactive power as gross values, and voltage and frequency measured in the connection point. For monitoring purposes in case of large deviations of frequency or voltage, it is required to implement local data acquisition at a sampling rate of 0.5 sec. additionally, to improve power system supervising; the CTU/TSO should installed PMUs in key 220 & 400 kV transmission substations. The target was tie-lines as well as substations close to large scale generating units or renewable energy sources. Operating the power system closer to its stability limits imposes a more accurate monitoring - in order to avoid system frequency or voltages instability due to system contingencies. The monitoring objectives are the active power reaction, at deterministic frequency deviation, and the inter-area propagation of low frequency oscillations inside the control block. An algorithm needs to be developed from all records, of Power Plants and PMUs are analysed in a comparative manner.

The actual PMU applications:

- Power System Observability Improvement - Using accurate on-line measurements of voltage magnitude and angles and monitoring the active power flow on interconnector lines enables a more accurate estimation of the power system steady-state stability, and allows for active preventive action.
- Power System Oscillation Detection using the PMUs, inter-area oscillations can be detected and properly analysed online; additionally, countermeasures to damp them can be taken by the operators, if needed.
- State Estimator Validation - The power system is currently supervised on a quasi-state basis using asynchronous measurements received from transmission substations. Operator actions are based on the results of the state estimator. A cross-check of the state estimator evaluation and the online real synchronized measurements will contribute to measurement accuracy.

In the future, power system control and protection (voltage control, load shedding, Sections Island, pole slip back-up protection, neighbouring power systems separation, etc.) can be implemented based on increased experience using the synchro phasor techniques.

Conclusions and Recommendations

Large-scale RES integration will be displacing a significant part of conventional fossil sources of generation. Consequently, it is necessary to acquire stability and system inertia from the RES as a condition for operation; additionally RES must support services such as active power and voltage control. Starting from the specific example of RES development in India and in consideration of Indian requirements, the Indian Transmission utilities, planners and regulators have developed technical connection requirements, operating structures, and market rules - allowing for maximum flexibility of current RES technology.

TSO encourages and sustain all form of RES but provision of ancillary services are still to pick up and encouraged for wider area stability. We are at the onset of the process, but the main direction to establish and that kind of aggregation, involving distributed or concentrated units in same region, represents the first real, concrete and functional step, on the road map of smart grid in generation field.

When observing the requirements regarding reactive power and voltage control loops, RES have an important contribution to system stability and voltage control. Connection rules based on advanced technical solutions have increased the RES operational flexibility.

Frequency response control with different implementation solutions (reserve cluster), has an important role in sustaining the synthetic inertia - taking into consideration that more than 40% of total Generation from RES in targeted in Indian system and will has implemented by 2032.

The Indian planners, and regulators along with TSOs are developing a specific operation structure, observation system, and control system for all RES by a project named as REMC (Renewable Energy Monitoring centres). This framework is based on creating flexibility and emulating functions provided by classical units. Indian system has to implement both market and technical rules -such as observability and control - in order to operate a huge amount of sources characterized by a high variability. All the presented solutions represent the emergence of a smart grid framework in future.

Power system operators need to develop a broad understanding of the policy objectives that will materially affect the operation of the power system. There is a concern that many of the limits to RES integration will be because of the fundamental shift to non-synchronous variable generation, which may manifest itself in voltage stability, reactive power and transient stability. We need to establish mechanism of where RE Generators can emulate the behaviour of conventional rotating machines in stabilizing the system.

A strict adherence to Grid Code provisions is required and enforcement is needed. However, legacy issues regarding Grid Code enforcement may prove to be a problem in the future, possibly dragging down overall penetration of RES. The increasing levels of RES will fundamentally change the characteristics of power systems across the world. In order to manage these changes, system operators will need greater system performance, which might include system flexibility through demand side management and smart grid initiatives, more active studies and actions are needed to be create artificial inertia into the system.