Controlling Power Generation and Ancillary Services from Variable Renewable Energies (Wind and Solar) in India

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***Abstract*—Currently India is in the process of converting their power system towards higher shares of renewables. Grid stabilization tasks, formerly exclusively carried out by very large power plants, will in the future have to be obtained by renewables as well. Since retrofitting is usually complicated and cost intensive, the foundation for save grid integration of variable renewable energies must be laid out today. In this regard India can immensely profit from the experience gained in countries with already high shares renewables to avoid making the same mistakes.**

Therefore the objective of this paper is to give recommendations on the current Indian Grid Code framework, to include renewable power plants in grid stabilization schemes (Ancillary Services) based on international best practices. These are based on results of a GIZ funded project, where the possibilities to control active power and the provision of ancillary services with renewable energies in South India were compared with several international experiences.

A provision of Ancillary Services (AS) is especially important in India since the majority of conventional power plants operate under Power Purchase Agreements (PPA). These usually do not include Ancillary Service measures. With a rise of volatile renewable energy generation the need for Ancillary Services increases as well. As a consequence these plants will have to provide Ancillary Services themselves, even though provision of AS often is cheaper with conventional generation (fuel cost savings), if not restricted by PPA's.

One of the main recommendation is to include all power plants connected to the medium voltage grid and above into the Indian requirements currently set up only for large generators. In the future all generators (except low voltage level) should be remotely controllable, to adjust setpoints and have all operation relevant variables available at the grid operator level. Further, new plants should be capable of automatic frequency and voltage control. Only with these requirements in place fitting market structures for Ancillary Service provision via renewable energies can be effective. Currently Indias Energy Market is not well advanced and several steps need to be taken before a robust AS-market scheme can be put in place. Therefore, both market and technical capabilites have to mature simultaneously in order to be ready once safe grid operation, without Ancillary Services provided by renewable energies, is no longer possible.

I. Motivation and Introduction

The purpose of this paper is to provide recommendations on the future Indian Grid Code and corresponding market designs to include wind and solar farms in Ancillary Service provision schemes. The underlying project was funded by GIZ India and carried out by a consortium of four companies, namely Energynautics, energy & meteo systems, Teri and Ecofys.

A clearly structured, state of the art Grid Code is essential for stable grid operation especially under rising shares of renewables. India's Grid Code is currently under revision and it therefore provides a good opportunity to improve the current situation, where AS are only procured from a few very large power plants.

Even though this paper focuses on Ancillary Service provision with renewable energies the proposed requirements should also be requested from newly commissioned conventional power plants. Otherwise an unfair burden would be placed on renewable power plants.

The scope of this work are renewables connected to voltage levels larger than 10 kV (medium voltage and above). For each analyzed Ancillary Service measure the current status in India is compared with the typical requirements of other countries with high shares of renewable energies [1]-[28], resulting in specific Grid Code and market recommendations. Renewable power plant penetration rates are still relatively low, however there is a strong increase expected in the near future, as there are high political targets defined in the Indian renewable development plan. Contribution of variable renewable energies towards system stability thus will become increasingly important. To avoid the risk of complicated and often expensive retrofitting, the capabilities should be implemented already today, even if not used right away. Therefore, the Grid Code recommendations presented in this paper provide a guideline to future-proof India's power supply system.

Chapters II and III respectively introduce frequency and voltage related requirements. Possible retrofitting measures are investigated in Chapter V to improve existing power plants, since new requirements usually only are applicable to newly commissioned generators. In Chapter IV the importance of compliance testing is discussed, while Chapter VI summarizes the recommendations and main conclusions.

II. Frequency and Reserves

In an AC power system, load and generation must always be equal. Imbalances lead to frequency deviations, if generation exceeds load, frequency rises and in the opposite case, frequency drops. Frequency is a global value across the entire synchronous area, so load and generation must be balanced in the entire zone. As forecasts of load and renewable generation are never 100 % accurate, system operators have to allocate operating reserves to balance out fluctuations. These are split into three time dependent subgroups. Frequency Containment Reserve (FCR, primary reserve) needs to be fully activated within 30 seconds, while Frequency Restoration Reserve (FRR, secondary reserve) becomes fully activated in 5 to 15 minutes. Last Replacement

Reserve (RR, tertiary reserve) is then manually activated to free the FRR for new events. This concept is currently being implemented in India as well, but corresponding markets are not set up completely yet. Also some requirements specific to renewables have to be put in place to enable reserve market participation. Therefore, the consortium proposes three main recommendations to be included in the current Grid Code revision to set the course toward AS-markets for renewables:

- In case reserve products are defined technology independent as requested by the Central Electricity Regulatory Commission (CERC), the specific properties of renewables need to be considered in the market design schemes. If the definition of timelines, prequalification criteria and verification procedures is tailored towards the properties of conventional generation only, these criteria might need to be changed in the future again to include renewables.
- Lead-times for the reserve markets should be as short as possible, although it increases the operation effort. Contract periods of a month or a week would effectively exclude the possibility to provide reserves from renewables. Experience from Germany has shown, that adjustment of the lead times from months to a day can lead to a higher supply of reserves and consequently lower prices.
- Detailed system studies could help to identify the point in time, where primary and secondary reserves from conventional generators become scarce. As soon as this is the case renewables have to take over to provide reserves. As this situation might arise already within the lifetime of renewable generators installed today, it is inevitably, that the technical capabilities for communication and control are required already today. Especially with the high shares of PPA, this situation might come sooner than later.

In addition to frequency reserve provision further capabilities have to be met. Generally, power plants have to stay connected to the grid even at big frequency variations. The current frequency band of constant connectivity of 47.5-52 Hz in the Indian Grid Code are sufficient, but should also withstand a rate of change of frequency of at least 2 Hz/s, such as is already a requirement in the Indian Grid Code.
While frequency reserves should be enough to keep the frequency within the operation dead band, emergency measures are necessary in case the frequency drops even further. Limited frequency sensitive mode (LFSM) is commenly used to change the active power output of the plant in case of larger frequency deviations to bring the frequency back ito its nominal value. As an emergency measure LFSM is not reimbursed in any analyzed Grid Code.
Two types of LFSM exist, namely over- (LFSM-o) and under frequency (LFSM-u) active power control. In case of over frequency, all power plants must reduce their active power output to reduce the grid frequency. Active power increase in the event of under frequency (LFSM-u) is a different matter. Only plants running in curtailed mode can increase their output. An exemplary control curve consisting of both under- and over frequency is displayed in figure 1.

Currently in India LFSM-o/u is only a requirement for power plants larger 10 MW connected to 33 kV power lines or higher voltage levels. We do recommend to require LFSM also for smaller units connected to lower voltage levels in

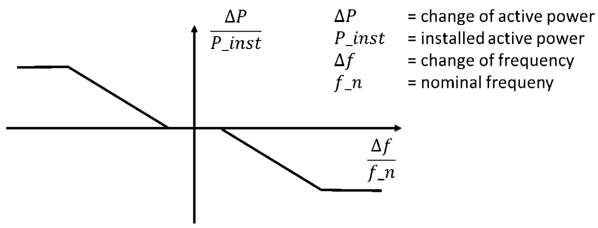

Fig. 1. Exemplary frequency dependent active power change control characteristic for under and over frequency deviations (LFSM-o/u)

order to improve grid stability. Also the dead band needs to be freely changeable in an area of $\pm$ 0.6 Hz of the nominal frequency and the steepness of the adjoining slope adjustable within 2-12 % as is not the case yet. This measure comes at little extra cost, since it is software dependent, but enables high adjustability in case of grid improvements. Further, an automatic active power response to a frequency deviation needs to be fast enough to keep the deviation as small as possible. Depending on the technology the following values are proposed in accordance to the current international best practices. The settling time should be below 10 seconds for photovoltaic systems and 30 seconds for wind generators. The maximum rise time until 90 % active power change should be set at 1 second for photovoltaic systems. Wind generators will only have to provide a rise time of 5 seconds at a reduced power change of 40 %. Figure 2 shows the dependencies of rise and settling time in general terms. These reaction times are very important to avoid system frequency swings in decentralized power systems, which might occur with high shares of renewables and therefore should be included in the new Indian Grid Code.

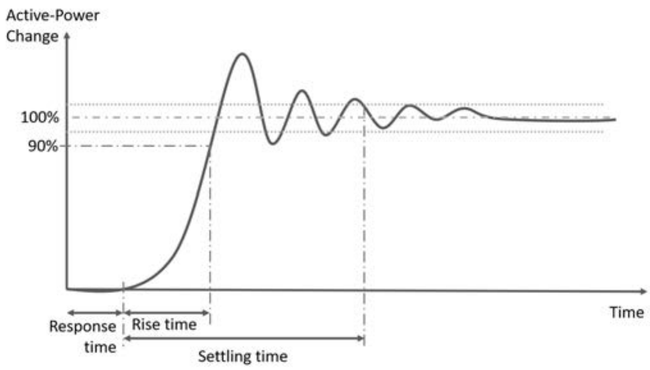

Fig. 2. Illustration of different control relevant times.

Due to the limitations of LSFM-u and the long revision times of the Indian Grid Code an additional capability, called Delta-Control, should be required. Delta controlled units can run at a predefined delta below their maximum available output power and thus can provide additional active power in case of a frequency drop. For wind and solar generators, the challenge is in knowing the available upward reserve at all times. In India, Delta Control will become especially important, since many conventional power plants are subject to power purchase agreements and usually do not include upward reserves. At the moment only the Delta Control capability should be a requirement without providing the

margin of error for upwards reserve provision and other values. These can be added through a Grid Code amendment, once deemed necessary. A committee consisting of national and international experts should be formed to determin the exact values.
In general terms wind and solar power plants will have to become more flexible than they are required to be by today's Grid Code. Once aspect is to demand remote controllability of all generators. It is the basis for advanced Ancillary Service markets. Currently the Indian Grid Code only requires a direct communication link to power plants with an installed capacity larger than 500 MW. For smaller plants with a size above 10 MW, indirect change of setpoints via e.g. a telephone call to the plant operator is sufficient. Below 10 MW no setpoint change capabilities are necessary at all. In the future Grid Code all power plants connected to the medium voltage level and above will need to provide remote control options. For example in terms of frequency related issues, the grid operator will need to be able to change the active power and all related control parameters, while being provided operation data, such as frequency, curtailed and maximum feasible current active power output. The new active power setpoint will have to be reached with a maximum power change rate of 0.33-0.66 % to avoid instabilities and finally should not deviate from the setpoint more than 2 % of its nominal value.

III. Voltage and Reactive Power

VRE generation may impact voltage quality in different ways, depending on the type of installation. Inverter based generators are technically well suitable to control voltage by varying their reactive power output. The voltage needs to stay within a predefined dead band. Voltage control from VRE generators is commonly also required from smaller generation units to counteract grid fluctuations and to keep the voltage within its limits. Voltage control via reactive power is not an explicit part of the Indian Grid Code, yet, but should be added within the ongoing Grid Code revision. Power plants usually have to be able to provide reactive power within a given range. The required reactive power range does not necessarily correspond to the actual use of reactive power from generating units. It is merely a precondition to get connected. At medium voltage level and above the required reactive power capability is typically independent from the active power output instead of a specific power factor. This is recommended to be required in India, too. Usually, the maximum reactive power requirement is in the range of $\pm$ 33 % of the installed active power corresponding to a power factor of cosphi = 0.95 under full load. As a consequence, high power factors are necessary at low active power output to provide the required reactive power. To reduce costs, below 20 % of the nominal active power output, the reactive power requirements are reduced. For similar cost saving reasons, some Grid Codes allow reactive power reductions above 80 % of the nominal active power. Since in situations of nominal active power infeed, reactive power infeed often is most critical, the consortium discourages the described reactive power reduction at high power infeed. Consequent boundaries are shown in figure 3.

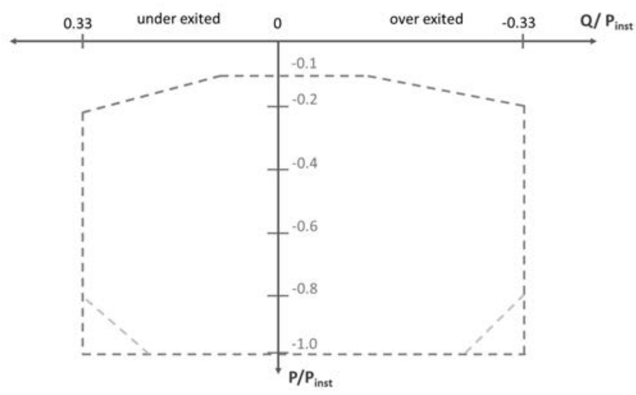

Fig. 3. Typical reactive power requirements in medium voltage grids and above.

Under consideration of the required reactive power range the actual reactive power can be set according to various control schemes. The most common control scheme, at the medium voltage level and above are either fixed reactive power output or voltage dependent active power changes (Q(U)-control).
Fixed reactive power output setpoints need to be adjustable by the grid operator, to account for grid load changes. Due to the increasing number of plants high shares of renewables doing so by telephone calls is not feasable anymore. Remote control capabilities must therefore be included. In case of an reactive power setpoint change, transition shall be conducted with a defined maximum ramp rate to avoid instability. Especially in the case of high photovoltaic penetration levels with little system inertia, this could prove critical. The required settling time is usually in the range of 5-60 seconds and needs to stay within 2 % of the nominal value. The exact value should be provided by the grid operator depending on the local grid topology. Further, a switch of the operation procedure to voltage dependent reactive power control should be done remotely, including a change of control parameters.
As specified by the name, voltage dependent reactive power control will change the reactive power depending on the current voltage to achieve the desired voltage level. Typically, voltage dependent control includes a dead band around the nominal voltage with droop to both sides of varying steepness. In some situations, it makes sense to move the dead band to other voltage levels as displayed in figure 4, in order to e.g. reduce grid losses. This feature should be required for all generation units connected to medium voltage and above. Implementation cost of the extra measure are expected to be low, since it is software related.

For a change in reactive power due to voltage deviations save reaction speed is necessary to avoid instabilities. Following PT1-Filter behaviour the maximum settling time capabilities should be below 5 seconds, but the grid operator can ask for larger values of up to 60 seconds, even after the plant is commissioned, as the best value depends on the local grid topology. Slower reaction generally reduces the risk of swinging effects, while fast reaction stabilizes the voltage more efficiently for example in case of short circuits.
By including reactive power control into the Indian Grid

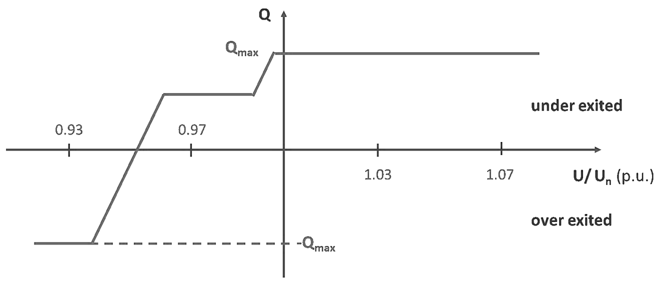

Fig. 4. Possible configuration of a Q(U)-control characteristic.

Code clear guidelines are set up to keep the voltage within its limits, however the question of reimbursement remains. Almost no country has established reactive power markets. In Great Britain such a market exists, but only with debatable success, since reactive power is bound locally. Since India's overall power market structure is not well developed yet, voltage stabilization should be a general requirement for all generators connected to the medium voltage level and above. Even without a market it could be reimbursement at fixed prices, although the consortium proposes to have no remuneration for reactive power control, since it is a local attribute and therefore directly helps the connectivity of the plant.

IV. Grid Code Compliance

The grid operator needs to ensure compliance of generators with the Grid Code. Without enforcement mechanisms, there is little use in setting requirements. The most important aspect, regardless of the legal framework, is, that the grid operator is able to deny power infeed of non-compliant generators at any point of time until the problem is fixed. To avoid abuse such actions will have to be documented in a clear manner.

There are three general ways of ensuring compliance of either a power plant or a single generating unit, either by declaration, certification or by actual testing. Testing compliance of a power plant after construction is usually easy and feasible for requirements that are applicable during normal operation, such as active and reactive power control, reaction to remote control signals via SCADA etc., but fault behavior is hard to test especially for larger installations. For countries such as India comprehensive testing is not yet an option, but should be developed until the following Grid Code revision. For now, these regimes are recommended for the Indian system:

- As to not artificially limit the number of suppliers in the generator market, it is recommended to align the major Grid Code requirements with those from larger countries/markets. In case PV or Wind-generator types have already been proven grid compliant under similar Grid Codes (mainly Europe: 50 Hz and comprehensive testing) no more compliance tests are necessary. Still it should be verified if all required functionality is activated and parameters are set according to the Indian Grid Code.
- Grid code compliance verification through the use of models is the best way of testing short circuit and low voltage ride-through capabilities of power plants without actually having to go through the procedure of setting up a short circuit in the transmission grid. Such capabilities should be developed starting with the largest power plants. Models have to be adequately verified to be used for compliance verification. This requires either the setup of a certification process as in Germany, or the verification of the models by the grid operator themselves, based on data delivered by the manufacturer.
- Actual short circuit tests may still be conducted on especially system relevant units, if deemed necessary by the TSO.
- For smaller installations or power plants composed of multiple smaller units, such as wind power plants, a simplified procedure can be used. If the manufacturer can prove in a lab installation that a single unit fulfils the Grid Code requirements for fault cases, there is no reason why an installation composed of multiple units should not be considered compliant as well.
- Operational aspects should be tested by the grid operator upon grid connection, such as:
    - o Remote controllability of Active/Reactive Power
    - o P(f) & Q(U) setpoints
    - o Rise times in case of new setpoints
    - o Rise times in case of voltage or frequency change

Once grid connection is finally approved, the grid operator has the right to run ex-post compliance tests. The plant operator has to provide a backlog of all setpoints, measurement data and output values three month backwards upon request. The cost of the data provision has to be borne by the plant operator. In case misbehaviour is detected the plant can be disconnected from the grid depending on the severity. If miscompliance has been intentional (e.g. not installing precise measurement equipment) additional fines can be applied. Once the plant operator can prove that Grid Code compliance is re-established, the plant needs to be reconnected.

V. Retrofitting Possibilities

As few South Indian states already have high share of wind and solar in their power systems, setting new ancillary service requirements only for new wind/ solar generators may not be sufficient. Retrofitting will also be necessary for existing wind/ solar power plants, as share of conventional power generation is being reduced in the grid.

As on 31-05-2019, South India has an installed wind capacity of 18,180 MW (MNRE). The GlobalData Power Plants Database contains manufacturer information for 14,600 MW of South Indian wind farms. It shows that Suzlon, Gamesa, Windworld, Vestas and GE make around 74 % of the wind capacity. The technical survey of these technologies was conducted. The survey shows that except Vestas V39 turbine model, all existing turbines have the capability of providing active and reactive power control. As per Global Data, around 137 MW of Vestas V39 are installed in South India. After turbines, the capabilities of wind farms' SCADAs/ control devices were studied. For this, interviews were made with the international technical teams of wind turbine manufacturers. Interviews suggested that none of the wind farms in South India have manufacturers' standard interfaces and control devices. So, there is no direct interfacing between the grid operator and the wind farm system. For passing power curtailment signal to wind parks, grid operator currently calls the park operator by phone. The park operator then manually and locally controls wind park with the proprietary solution provided by the manufacturer.

In order to implement remote automatic (re) active power control in wind farms, Park control device must be procured from respective manufacturer. In India, a wind park connected to a grid substation (with several individual wind farms) is generally developed by a single power developer who has central SCADA at the park level. So, this park controller is needed at the park level. The costs of park controller may vary between 25 -150 kEuro/ park, depending on the manufacturer.

As on 31-05-2019, South India has an installed solar capacity of 18,180 MW (MNRE). Interviews were conducted with 4 major South Indian power producers who make around 30 % of installed solar power in South India. It was observed that existing inverters have the capability of (re) active power control. All SCADAs are also found to have the capability to provide set points to inverters and interface with grid operators. However, no logic is currently implemented in SCADA to implement above. Currently, active power control is local and manual process in SCADA as discussed in case of wind.

In order to implement remote automatic (re) active power control in solar farm, there are 2 options. Option 1 is to implement necessary logic in the existing farm's SCADA, which will require around 20 person days of work per park (in addition to possibly little hardware costs or license cost (tentatively around 0-2 kEuro/park)). Another option could be to use an additional PLC (programmable logic controller) and implement necessary logic in the device to implement ancillary power control. This will require around 40 person days for development, and per integration it will require a hardware cost of 4 kEuro/park along with 5 person days work (for the farm specific integration).

The consortium encourages retrofitting of the existing wind and solar farms as far as possible. Fitting schemes have to be set up to encourage retrofitting. A suitable method is to provide incentives in the first years, while slightly reducing them over time. Once the majority of power plants has been retrofitted, penalties could be set up for the remaining systems. The retrofitting case of Germany is presented to provide an exemplary method, following the proposed guidelines. Before the year 2008, there was no liability on wind/ solar farms for having remote control capabilities in Germany. In year 2009, it was made mandatory for new wind parks to have ancillary power support. In year 2011, Germany started optional bonus of 0.007 Euro /kWh for 5 years for retrofitting reactive power control. Since year 2012, Germany has market premium model for power plants. Under this model, between 2012-2014, remote controllable plants received a bonus of 0.001-0.002 Euro /kWh. After year 2014, it was made mandatory for participating plants (in market) to be remotely controllable in order to get market premium.

VI. Summary and Conclusion

This paper describes the results of a GIZ funded project, where the possibilities to control active power and to provide ancillary services with renewable energies in India were investigated. Within the current Indian Grid Code framework already many basic requirements are included, but often only for larger generators. The main recommendation is to have all generators at the medium voltage level and above fulfil these requirements. Further, Q(U)control with fixed reactive power ranges should be added for all power plants at the medium voltage level and above. Also, maximum and minimum ramp rates have to be defined to avoid system instabilities through swinging effects. With an increase in renewable power plants, remote controllability of each plant is highly recommended. The grid operator will need access to the current operational points such as power output, frequency and voltage at the grid connection point. Also, corresponding set points must be changeable in an efficient manner without calling the plant operator. Even if not used right away, such measures should be included from the start to avoid expensive retrofitting cost. In addition to remote controllability of the plants, automatic voltage control via reactive power and LFSM are highly recommended to be added for each plant. Further, Delta Control capabilities should be required, without the necessity for highly accurate forecasting models, which can then easily be added at a later point. Finally, Grid Code compliance is an important topic within the pending revision, to make sure, that the proposed measures are enforced. Since Grid Code revision processes take a long time (and India is no exception), the basis to provide Ancillary Services with renewable power plants needs to be set today.

In some areas, due to already high shares of renewables, additional retrofitting becomes necessary, to avoid grid instabilities once conventional generation is reduced. The corresponding retrofitting cost are rather low and an effective scheme should be set up to upgrade these plants to comply with the new grid code as well.

Once the recommended technical capabilities are included into the renewable energy plants a functioning market can be designed to allow Ancillary Service provision by renewable energy plants. These market schemes will have to include suitable closing times and pooling options to reduce the risk of differing forecasts. With a simultaneously improved grid code and market design a big hurdle towards efficient reduction of green house gas emissions of the Indian power system will be overcome.

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