Pakistan

Study to Determine the Limit of Integrating Intermittent Renewable (wind and solar) Resources onto Pakistan's National Grid

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Executive Summary - November 2015

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1. Background and Scope of Work

As the amount of renewable energies (RE) in the electricity grid increases, new challenges emerge. Initially built for traditional power sources, the grid is not yet fully adapted to the foreseen levels of RE, and nor are the ways in which it is designed and operated. The Pakistan grid needs to be reinforced and better interconnected for higher system security and a more economical dispatch of power.

The aim of the "Study to Determine the Limit of Integrating Intermittent Renewable (wind and solar) Resources onto Pakistan's National Grid" is to provide answers to the following questions

- What is the maximum capacity of wind and PV plants that can be integrated into the system of Pakistan until 2016/2017 without the need for additional grid expansions?
- Which addition grid reinforcements and grid expansions are required for integrating up to around 5,5GW of wind generation and up to around 3,9GW of PV generation into the power system of Pakistan and how much does it cost?
- What is the impact of the variability of wind and PV on conventional power plants, in particular on required spinning and contingency reserves?
- Are existing operational processes, as defined by the grid code, appropriate for handling up to 9,4GW of variable renewable generation? Which operational processes require adaptation and which modifications are required in particular?
- What is the financial impact of the integration of up to 9,4GW of variable renewable generation into the power system of Pakistan?

For answering these questions, several studies have been executed. The results of the different studies are described in the following reports:

- Task A: Grid and system integration studies
- Task B: Operational studies
- Task C: Financial analysis

2. Main results

2.1 Task A: Grid and system integration studies

2.1.1 Grid impact studies

The Pakistan power system has been analysed for the installation of 4067MW of variable renewable energy in spot year 1. This figure was increased to 9332MW of renewable energy in spot year’s 2 and 3. This is an exceptionally challenging deployment, particularly considering the system load which is in the range of 15 to 30 GW over the years considered.

For the first year of investigation (2016/17) the analysis covered 4067MW of existing and planned wind and PV farms to be connected to the Pakistan power system (intended capacity)
Out of this intended capacity it was determined that 2224 MW can be connected without any major reinforcements, for example the construction of new overhead lines. However, this amount of generation does require the addition of some minor plant including:

- 25MVAr capacitor at Bhan Saedabd 132kV substation
- 120MVAr TCR Inductive 200MVAr MSC Capacitive SVC at Lal Suhanra
- Power System Stabilisers (PSS) at two synchronous generator locations (Hub and Jamshoro)

Additionally, the operation of some renewable generators in voltage droop control mode was identified to be beneficial.

In spot year 2 (2019/2020) there is the option for major system reinforcement, including additional transmission lines and transformers. Not only does this allow the full 4067 MW of renewable generation from spot year 1 to connect, but there is significant new renewable generation installed by this year resulting in a new total of 9332 MW of wind and solar power plants. This requires substantial reinforcement of the Pakistan power system.

In general, this reinforcement is split into two areas. One 220kV reinforcement in the mid-east of the country around the Lal Suhanra region where there is a substantial PV resource, and 500kV reinforcements in the south in the Jamshoro, Jhimpir and Gharo regions, known as the ‘southern wind corridor’.

The Lal Suhanra region requires reinforcement of the 220kV system where a new generation collection substation is installed (QSP), and two radial 220kV legs are closed to form a ring. Not only does this allow the full power of the PV to be evacuated, but it provides a significant increase in operational flexibility. These works require installation of 80km of 220kV double circuit line, 5km of 220kV single circuit lines, one new substation, and 5 additional 220/132kV transformers plus associated switchgear, substation bays etc. This was determined to be the most favourable (cost effective, and providing the most operational flexibility) option based on the information available to date.

The reinforcements in the southern wind corridor are even more extensive with the extension of the 500kV network to a new substation called Jhimpir New 2. This includes two new 220kV substations and installation of almost 90km of transmission lines (at 220 and 500kV). In addition, to support voltages in this southern region once a significant volume of synchronous generation has been displaced, a 200MVAr capacitor at Jamshoro, and 100 MVAr shunt capacitor at Gharo are required. Finally, a

600Mvar SVC (600MVAr TCR and 300MVAr TSC) is proposed at Shikapur 220kV to manage fast voltage variations due to the displacement of renewable generation and for ensuring that transient stability constraint export limits remain as high as in cases without renewable generation.

In addition to these two regions there are some further 132kV system reinforcements required for connection of the numerous dispersed and embedded renewable generators. However, most of these can be achieved with uprating (by re-conductoring) of existing lines. There is also a recommendation for the new generator at Engrothar to be fitted with a power system stabiliser (PSS).

An overview of all proposed grid reinforcements is contained in Annex W of the Task A report.

The dynamics cases in spot year 2 and 3 have identified the need for several modifications to the gird code of Pakistan to allow the significant renewable generation in these years to be successfully integrated, and to ensure that they actively support the power system. These recommendations are summarized in the report relating to Task B.

Considering the proposed grid reinforcements and modifications to the grid code for wind and solar power plants, the dynamic response of the power system is good, especially considering that for some cases analysed, over 47% of the load is supplied by wind and PV alone.

With the modifications described, and provided the new renewable generation complies with the grid and distribution codes of Pakistan, plus the high level additional performance characteristics described in this report, it can be stated that this substantial volume of renewable generation can be successfully integrated to the power system in a stable and secure manner.

2.1.2 Flexibility studies

The power system of Pakistan has been analyzed with respect to flexibility aspects. This analysis was mainly focusing on the increased requirements with respect to operational reserve and ramping requirements of hydro and thermal power plants resulting from the variability of wind and PV generation.

Based on the studies presented in this report, we can make the following statements:

- The correlation of wind and PV generation with system load in Pakistan is good, and wind and PV will substantially contribute to a reduction of required load shedding.
- In 2016/2017 the increased uncertainty resulting from wind and PV generation can potentially lead to increased unplanned load shedding, while reducing the overall amount of required load shedding significantly.
- In 2019/2020, the maximum amount of spinning reserve will be in a range between 1000MW and 1500MW, and between 200MW and 400MW on average, depending on permitted load shedding (or demand-side response). Without the contribution of wind and PV generation, the maximum amount of required spinning reserve would be around 1000MW (and between 150MW and 350MW on average). Hence, the impact of wind and PV generation on the maximum required reserve power is around **500MW**.

Consequently, the recommendations for spinning reserve according to OC 5.2 should be seen as minimum requirements and spinning reserve should be carefully predicted using state-of-the art wind and PV prediction tools.

For reducing the required spinning reserve when integrating large amounts of wind and PV generation, the following actions can be taken:

- Re-execute wind and PV prediction at 4hour-ahead and/or even 1hour-ahead of real time.
- Shorten the dispatch cycle from 30min to 15min.

These are explained in more detail below.

Re-execute wind and PV prediction at shorter prediction intervals:

A re-execution of wind and PV prediction at 1hour ahead of real time allows predicting wind and PV generation at substantially higher accuracy than a day-ahead prediction. Such an additional prediction would allow compensating part of the day-ahead prediction error using contingency reserve instead of spinning reserve: When executing an additional 1hour ahead-of-real time wind and PV forecast process, the difference between the day-ahead prediction and the 1hour ahead prediction of the residual load would be compensated by contingency reserve and only the 1hour ahead prediction error (+ variations within the 30min dispatch interval) would have to be compensated by spinning reserve.

This concept could be further developed by introducing an additional 4h ahead re-dispatch process allowing additional thermal generators to be started and synchronized, serving as slow reserve for compensating the difference between day-ahead and 4h ahead prediction errors.

Shorten the dispatch cycle

Shortening the dispatch cycle, e.g. from 30min to 15min would help reducing systematic errors resulting from continuous variations of wind and PV generation (and load) within a single dispatch interval. Consequently, the required amount of spinning reserve could be reduced.

2.2 Task B: Operational Studies

2.2.1 Technical Capabilities of Wind and PV Plants/Recommended grid code changes

The first part of the report relating to Task B is dedicated to an overview about technical capabilities of wind and PV farms, in particular with regard to

- Reactive power capability
- Reactive power/voltage control capability
- Low voltage ride through capability
- High voltage ride through capability
- Dynamic voltage support during grid faults
- Frequency sensitive operation (contribution to primary and secondary control)

This overview shows that modern wind and PV farms have a technical performance which is comparable, or in some aspects superior, to the performance of synchronous generators (e.g. wind and PV farms don't have any rotor angle stability problems).

However, even if these features represent standard technology in many countries and don't drive up project costs significantly, these technical features will only be used and provided by wind and PV project developers if they are actually required by a grid code.

Consequently, the proper definition of grid connection conditions and procedures for verifying compliance of wind and PV farms with these requirements is key to the successful integration of large amounts of wind and PV farms.

In Pakistan, the Nepra Grid Code Amendments for wind generation and solar generation provide these specifications. However, the results of grid integration studies have shown that in order to ensure a secure and reliable operation of the system with even very high levels of wind and PV generations, these requirements have to be modified and complemented, which can be summarized as follows:

- Each wind and PV power plant having a POC at 132kV or above must be able to operate in either power factor, reactive power or voltage control.
- Low voltage ride through (LVRT) capability must be extended to faults with a retained voltage at POC down to 0,1 p.u. (instead of 0,3 p.u.)
- High voltage ride through (HVRT) capability
- During LVRT situations, wind and PV farms must be required to inject reactive current for supporting the voltage (dynamic voltage support)
- It must be ensured that active power recovery of wind and PV power plants is in a range between 2s and 5s so that both, transient stability and frequency stability is ensured in the case of faults at 500kV transmission lines in the south of the country.
- It must be ensured that there is no reactive power absorption during voltage recovery.
- A basic high frequency response shall be required as a mandatory requirement

Details about the recommended changes are described in the report relating to Task B.

2.2.2 Short-term operational planning and dispatch strategies

This chapter of the report relating to Task B describes general procedures for a successful integration of wind and PV in the operational planning processes of Pakistan.

Essentially, supposing that there is sufficient generation capacity again from 2019/2020 on, the integration of wind and PV into dispatch processes can best be described by understanding wind and PV as negative load, which is subtracted from the actual load. The remaining part of the load is named 'residual load'.

Essentially, all existing short-term operational planning processes can still be applied considering that instead of actual load, residual load must be supplied by hydro and thermal generation.

For improving system operations in the case of very high levels of wind and PV, the following recommendations are given:

- Introducing intra-day re-dispatch processes (e.g. 4 hours ahead). This will reduce the required amount of spinning reserve and very fast starting contingency reserve.
- Reduce dispatch cycles from 30minutes (as defined by the grid code) to 15 minutes. Shorter dispatch cycles will reduce variation of residual load with a dispatch cycle and consequently reduce the required spinning reserve
- Introduce professional wind and solar prediction tools in day-ahead and intra-day scheduling processes. An increase accuracy of wind and solar prediction can considerably reduce spinning reserve requirements.

Besides generation scheduling, the report also discusses the impact of wind and PV generation on frequency control and voltage control and gives recommendations for optimized voltage control concepts.

2.2.3 Wind and PV forecast

The third part of the report for Task B is dedicated to wind and PV forecast methods, available tools and service providers. The resulting recommendations can be summarized as follows:
It is quite likely, that the best option for Pakistan is to work with two or three companies in the field of wind and PV forecasting; One provider that merges all the different data within a software, that can simulate Pakistan’s' National Grid and other service providers that are specialized on Weather Forecasting and Renewable Energy production in South Asia.

To estimate the quality of forecasting in Pakistan in general and the accuracy of different providers in detail it is recommended to do an independent validation study with a few FSP's.

2.3 Task C: Financial Analysis

2.3.1 Objective and scope

The purpose of the financial analysis is to show the financial impact of the integration of wind and solar energy sources on Pakistan’s overall energy mix, and on the end user’s basket price.

To enable the comparison, two power generation expansion scenarios where developed which would fulfil Pakistan’s energy demand from 2015 to 2035:

- the first scenario was planned without Wind and PV Power Generation and
- the second scenario with Wind and PV Power Generation

For the development of the two scenarios, assumptions had to be made regarding the level of development of each energy source and the utilisation factors in the overall energy mix required in order to fulfil the demand in energy during the timeframe 2015-2035. These two scenarios are provided in Annex 1a (without Wind and PV) and Annex 1b (with Wind and PV) of the Task C report.

The maximum possible Wind and PV Capacity to be installed was based on Task A of the study which looked at the technical limitations of the power network for integrating Wind and PV power from 2015 to 2022. After 2022 a general increase in Wind and PV capacity of 6% per year contributes to the increasing demand.

Based on the developed scenarios, the costs of the different energy sources could be calculated and included investment in new capacities, operation and maintenance costs, fuel costs and transmission costs.

2.3.2 Results

The results of the financial comparison of both scenarios are clear: the integration of Wind and PV Power is highly beneficial for the Pakistani Energy Mix and for the end user’s basket price in both the short-term and long-term.

Load Shedding

In the short-term, the Wind and PV Capacities will lead to reduced load shedding and the economic value each kWh generated by wind and PV is equal to cost of unserved energy (or cost of fuel for the most expensive plants in the system).

Economic Value

In the long term, the economic value of Pakistan's power system (energy costs and revenues) is higher when it includes Wind and PV Energy. This is shown by the calculation of the Net Present Value (NPV) which considers that money devaluates over time.

The economic value can also be expressed in terms of an interest rate that an investor would gain if he invested in a project. This rate (Financial Internal Rate of Return) is higher for the scenario with Wind and PV than without. This is true even without considering the positive impact of Wind and PV on their contribution of lowering the load shedding.

Investing in Wind and PV is less risky

Prices for fuels used for power generation such as Oil, LNG and Coal are very volatile and fluctuations can have dramatic impacts on the energy costs which would lead to increase of electricity tariffs for the end user. In contrast, Wind and PV Energy costs depend on variables with much lower fluctuations

Furthermore, the total fuel costs are reduced with the integration of Wind and PV power which reduced the dependency on imports for the country.

Tariffs for Wind and PV power can decrease

The calculation of the unit costs of energy produced (the price for one kWh) for Wind and PV are lower than the current tariffs applied in Pakistan for Wind and PV Energy. This means that there is still a high potential for costs of Wind and PV Energy to fall. The present study is not a tariff study but shows that there is indeed a strong potential (see Chapter 1.3).

Low share of transmission costs

The costs for integrating Wind and PV power reach only 2.5% of their generation costs (calculated over the period 2015-2022).

3. Overall Summary

Overall, the studies show that until 2016/2017 a total amount of 2,2GW of wind and PV generation can be integrated into the national power system of Pakistan without any major grid upgrade.

Until 2021/2022 it is possible to integrate all of the planned 9,4GW of wind and PV generation. In order to do this, numerous grid reinforcements at 500kV, 220kV and 132kV will be required, which can be realized at moderate overall cost when comparing costs of these grid reinforcements by the economic benefit of wind and PV in Pakistan.

Besides strengthening the grid, it is required to modify the grid connection code for wind and PV. This is required for maintaining voltage and rotor angle stability at similar levels as today. It shall be noted that all stability studies have been carried out under the assumption that the recommended changes to the grid codes will be implemented and that future wind and PV farms will comply with these requirements.

The impact of variability of wind and PV has been assessed and its impact on contingency reserve and spinning reserve has been evaluated. The result of this assessment is that there will be increased spinning reserve requirement but which is in an order of magnitude that is manageable. Additionally, spinning reserve requirements can be reduced by introducing additional intra-day prediction and generator dispatch cycles and by reducing the dispatch interval from 30min to 15min.

The financial analysis leads to the conclusion that the integration of wind and PV will reduce costs compared to a system in which no additional wind and PV capacity will be installed. This holds true even when not considering the equivalent cost of load shedding.

Consequently, it can be said that the increased use of wind and PV for generating electricity in Pakistan represents a very interesting option for resolving Pakistan's energy crisis. When strengthening the grid appropriately and when implementing the recommended grid code changes and operational procedures, the use of wind and PV represents a cost effective option for generating electricity in Pakistan while maintaining system security at the required levels.