Power Flow Analysis of Distribution Systems with Large-Scale Wind and Conventional Energy Generation

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Abstract.

This paper is devoted to the development of a methodology suitable to be used to determine the impact of the grid integration of wind farms in distribution networks that are also supplied with other classical generation facilities based on thermal and hydraulic energy.

The methodology is based on an automated analysis system that varies the level of the electric generation for both the hydraulic and thermal generators by using *PSS*, *Phyton* and *Matlab*. The user can define multiple scenarios considering wind, thermal and hydraulic generators so the line capacity can be computed and compared in order to know where the system bottleneck is located and which situations occur.

All the results computed can be analysed in a single or compared way by using tables and plots and considering the static rate of the distribution lines.

The developed system can also be applied to the computation of the sensitivity of the power flow to the variation of the parameters that define the power system.

Key words

Wind Energy, Power Flow, Grid Integration.

1. Introduction

The growing use of wind energy systems in the Spanish grid and their typical location far away from the transport network is leading to distribution networks that are closer to their limits. Nowadays, it is not unusual that some percentage of the wind farms have to be stopped because the distribution network reaches its maximum static capacity.

Solving this problem requires:

(i) to build/re-power new electric infrastructures that increase the capacity of the distribution network and/or (ii) to increase the rate of the power lines by using dynamic rates (ampacity).

This research work focuses on the development of a methodology and a set of tools suitable to evaluate the effects of several scenarios of generation in the behaviour of the distribution networks, especially those that are close to wind farms. It will also be considered the effect of other generation technologies such as Thermal and Hydraulic (see Fig.1). The methodology and software developed provides useful information that help to the Distributor System Operator (DSO) to determine the hydraulic and thermal generation maximum level that can be generated in order to avoid restrictions with the level of wind power in each moment.
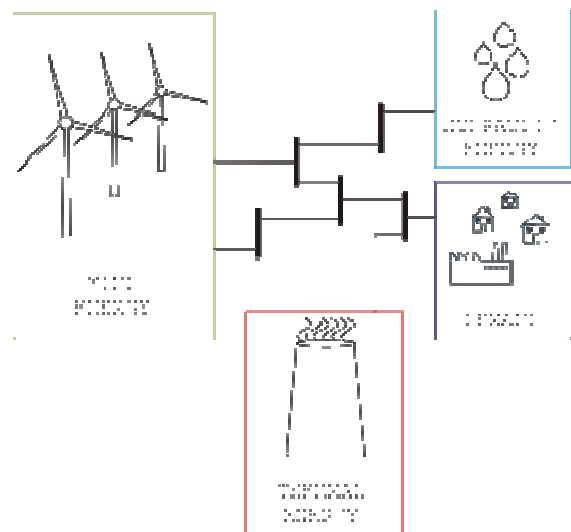

Figure1. Grid Scheme.

2. Grid Integration of Wind Energy

Grid Integration of Wind Energy to the Supply Grid distinguishes two cases:

1. Systems with limited short circuit capacity that operates in isolated mode or supplies weak grids.
2. Systems with unlimited capacity connection with the rigid grid.

The constraints related with the location of Wind Energy farms limit the availability of transport networks so it is not unusual to find distribution network with relatively low capacity close to this generation facilities. In these cases it is important to analyse the available capacity of this infrastructures with several operation scenarios.

3. Methodology

A. Automated Scenario Generation based on PSS, Python and Matlab

The methodology is based on the automatic generation of different scenarios by means of a power flow tool, a script generator and a powerful post-processing application: *PSS* (Power System Simulation), *Python* (Programming language) and *Matlab* (Matrix Laboratory).

The core of the system is *PSS*. It contains the equivalent model of the electric network that is going to be analyzed, and it also calculates the power flow. In this case, the analysis can be extended to the overall network or it can be limited to an extension that belongs to a small area in the network contained in *PSS* model with several levels of electric generation. This power flow is shown as a function of the power branch capacity.

It is necessary to do loads of simulations in *PSS* because the power flow balance changes with each variation of the generation. It is almost impossible to afford this task manually because of the time needed to set and run all the scenarios.
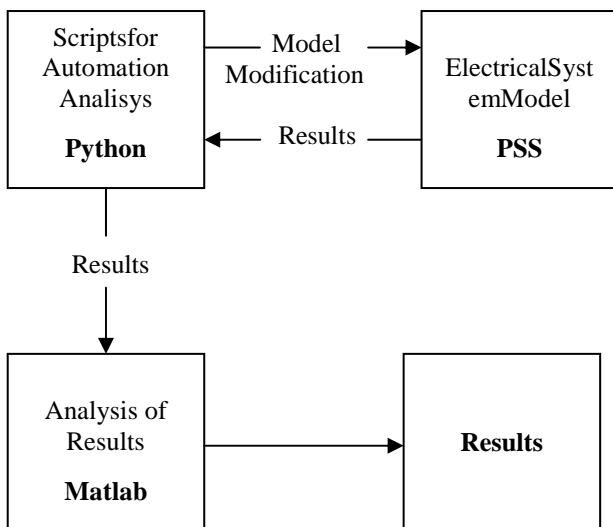

Figure 2. Methodology Flowchart.

In order to overcome this problem, some scripts written in *Python* have been used to automate the evaluation.

All the data obtained from each power flow simulation are stored in text files that can be used by *Matlab* to post process it graphically.

This automation application acts on the *PSS* electric network model enabling the user to change the level of generation of each generator in the network and determine the lines that the user wants to monitor. Once the overall model has been defined, *PSS* starts to solve the power flow considering several levels of wind power and store the results in text files(See Fig. 2).

Results provided by *PSS* are lists of numeric data, so they are difficult to analyze in order to see the behavior of the branch. For this reason the developed *Python* scripts calls a *Matlab* function in order to process the data, generating 2D plots and showing the power flow variation in branches with the increase of wind power. *Matlab* is also used to determine the level of wind power for which the line power reaches the saturation value or its limit of capacity.

Fig. 3 shows a piece of Python script code that can be used in order to automate PSS simulations.

```python
import sys
sys.path.append("C:\Archivos de programa\PTI\PSSE33\PSSBIN")
import os
os.environ['PATH']+=";C:\Archivos de programa\PTI\PSSE33\PSSBIN"
import psspy
import redirect
redirect.psse2py()
psspy.psseinit(100000)
_i=psspy.getdefaultint()
_f=psspy.getdefaultreal()
_s=psspy.getdefaultchar()


CASOraw= r""" C:\Dynelec\Trabajo\Asturias\Ter0\Hid50\net.raw """
CASOsav= r"""C:\Dynelec\Trabajo\Asturias\Ter0\Hid50\net.sav"""
SALIDALINEA="C:\Dynelec\Trabajo\Asturias\Ter0\Hid50\Salida.txt"
psspy.case(CASOsav)
psspy.fnsl([0,0,0,1,1,1,99,0])
psspy.save(CASOsav)


BUSEOL=[]
BUSNAMEOL=[]
nb=455
while nb<31906:
    if  11 == psspy.busint(nb,'AREA')[1]:
        BUSEOL.append(nb)
        BUSNAMEOL.append(psspy.notona(nb)[1])
    nb=nb+1


i=0
POTGENEOL=[]
while i<len(BUSEOL):
    Pg=psspy.macdat(BUSEOL[i],'1','P')
    POTGENEOL.append(Pg[1])
    i=i+1
f=open('C:\Dynelec\Trabajo\Asturias\Ter0\Hid50\Power_Wind_Gen.txt',"w")
f1=open('C:\Dynelec\Trabajo\Asturias\Ter0\Hid50\Wind_Bus.txt',"w")
f.write(str(POTGENEOL))
f1.write(str(BUSEOL))
f.close()
f1.close()
print POTGENEOL
print BUSEOL
```

Figure 3. Python script code used for automated PSS simulations.

B. Analysed Cases

Each case is represented by different rates of generation.

Wind generation will always take percent values from 10 to 100 in all cases while hydraulic and thermal generation remaining fixed. Depending on the number of thermal and hydraulic scenarios, multiple simulations will be performed. Table I summarizes the proposed methodology.

Table I. Analyzed Cases.

	Fixed Value	Variable Value	
Thermal Generation	0% – 100%	10% - 100%	Wind Generation
Hydraulic Generation	0% - 100%		

The cases that are summarized in Table I can be expanded to a variable number of simulations in an automated way that can be set by the user.

This approach can be useful in order to determine the bottleneck or the most critical points of the distribution network.

In addition, this approach can be used in contingency analysis (CA). In this case, the software uses a heuristic approach to study several scenario simulations in order to evaluate the impacts on the distributions system of different problems. From a general point of view, problems like the failure or loss of parts of the power systems (e.g. transformers of transmission lines). These kinds of failures are considered unplanned "outages". The proposed methodology can be used to:

- Evaluate the impact of the failures.
- Compute any overloads produce by the failures.

From the point of view of users, CA is basically a preview analysis tool that can be used in both off-line and on-line analysis. This tool helps operators to know the behavior of the system in uncommon situations.

4. Results

Fig.4 shows an example of one of the plots that can be generated. In this example, the level of charge in several lines is compared considering the same generation scenario (0% of nominal thermal capacity and 50% of nominal hydraulic capacity).
It can be observed that there are two lines exceeding their rated capacity at around 60% of wind generation (pink and black lines). It can be also seen that the other lines are less sensitive to the increase of wind generation, and can work below the rated capacity for all possible wind generation scenarios, especially in the case of yellow and sky blue lines.
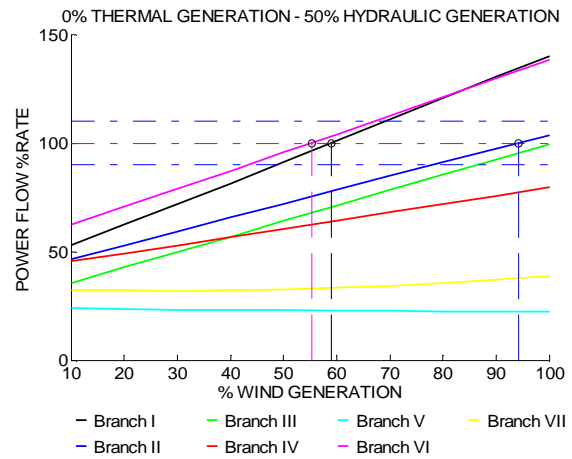

Figure 4. Branches in Same Scenario

In addition, Fig.5 shows the results only for the branch I. In this example, each curve represents the power flow as a percentage of the nominal line capacity (rate) for several levels of wind power and for a constant level of thermal and hydraulic power.
In this example it is also possible to notice that the worst scenario for wind generation is reached by the green curve (40% Thermal and 40% Hydraulic power), and the best scenario that allows to integrate more wind energy is for the yellow curve (10% Thermal power and Hydraulic power).
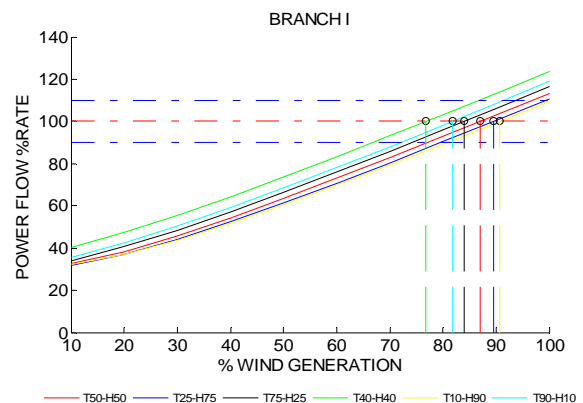

Figure 5. Branch behavior in several scenarios .

The results shown in figure 5 are conditioned by the topology of the analyzed network, because in this case the hydraulic and thermal generation plants are connected directly to the transport network of 400 kV and the generated power doesn´t use the distribution network. For this reason, the effects of different thermal and hydraulic generation scenarios are almost not observed in distribution network such as the one that it is indicated in Figure 5.

Fig. 6 shows the result of the contingency analysis of the type N-1. In this example the branch number II is open and the figure shows the rate in a specific scenario for the rest of branches.
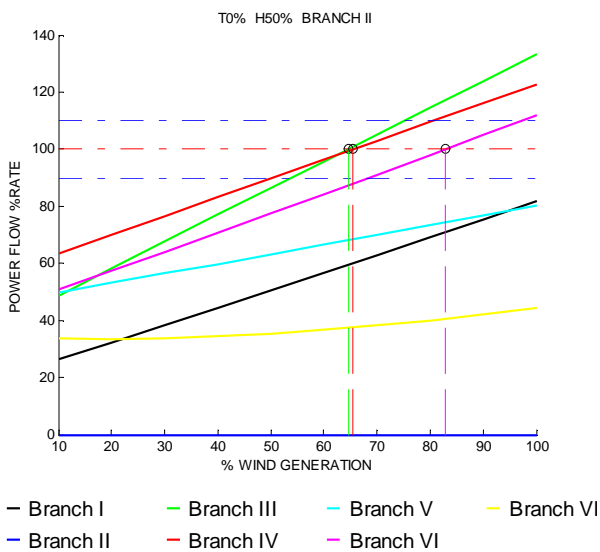
Figure 6. Contingency analysis.

5. Conclusions

This system works with any network modeled in *PSS* and can be improved to extend the type of analysis that can be performed because of the integration between *PSS*, *Python* and *Matlab*.

In this work the developed system has been applied basically to study the effects of the wind power penetration in the level of charge of several lines of a distribution network.

It can be also applied to the study of the effects of the generation level with other generation technologies maintaining fixed the wind power generation.

It is possible to extend the program to the contingence analysis in an easy way considering N-1 or N-2 scenarios.

Acknowledgement

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