EWEC 2003 (European Wind Energy Conference & Exhibition)

Profile of voltage in grids with wind farms

Universidad de Zaragoza

Joaquín Mur Ángel A. Bayod Jesús Sallán

University of Zaragoza – CIRCE Foundation – Electrical Engineering Department

Circe Centro de Investigación de Recursos y Consumos Energéticos

Abstract—Up to now, distributed generation in Spain must inject power with unity power factor. But directive is going to change and some feasible regulations for reactive power are studied, attending specially to voltages across the grid. The range of reactive power depends on generating technology and the wind parameters.

The proposed method can help to evaluate the affection to the profile of voltage and the availability of reactive power injection or absorption.

I. Introduction

Distribution networks are usually limited for the limits in voltage variation (specially at the end of the line). Therefore, distribution companies prefer distributed generation to be connected to higher voltage levels, where its impact in voltage profile is smaller. If reactive power is available, voltage fluctuations can be limited with lower cost. In addition, wind energy could reduce the losses in the grid if the zone has generation shortage (of active or reactive power).

II. Wind Farm Model

In this model, the farm is divided into the following parts:

- substation (including the park's substation and the portion of the line that goes to the PCC)
- the medium voltage network that connects the substation to the wind turbines.
- the wind turbines (including the MV to LV transformer)

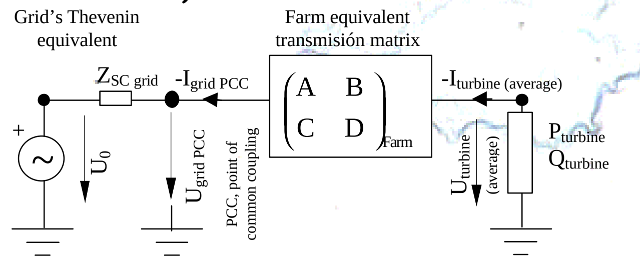


Figure 1: Model of the farm with fixed tap transformer using its transmission matrix. Final representation of the Wind Farm

Farm with tap-changing transformer

Substation voltage at the MV side of the transformer is almost the commanded value.

A.1 Added model of turbines using the model of moment

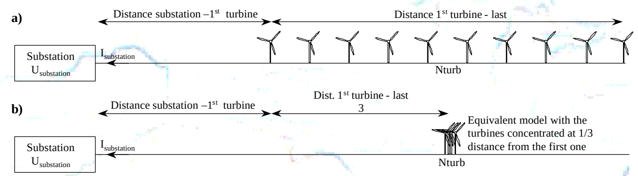


Figure 2: Concentrated model of a MV circuit in a park.

A.2 Model of the MV circuit branches

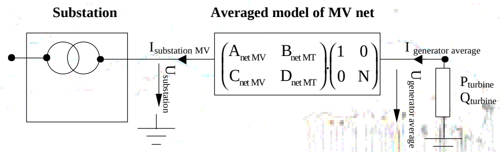
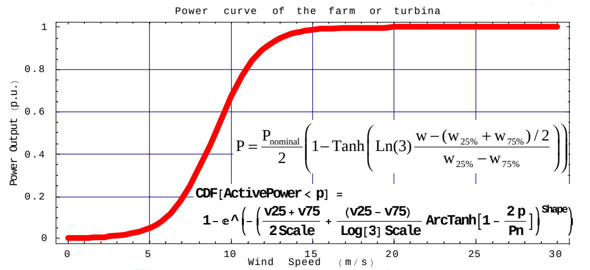


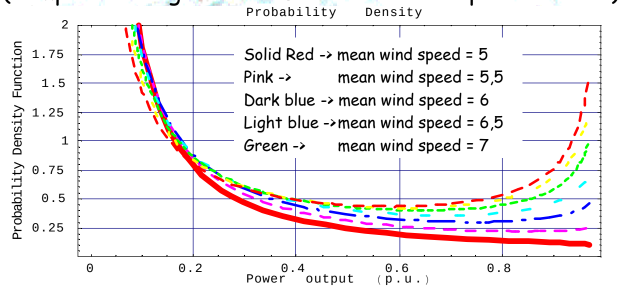
Figure 3: Simplified scheme of the medium voltage network of the park with added generator model.

Simplified power curve, defined by output of 25 % and 75% of nominal power

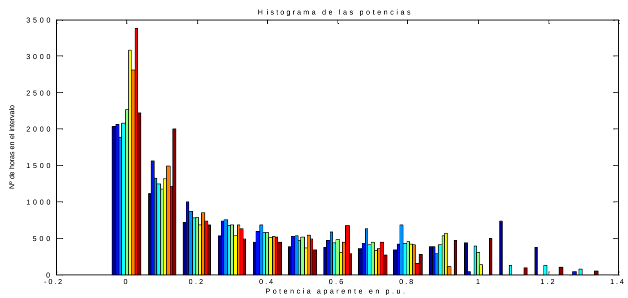


III. Distribution of Active Power Output

(computed using Weibull Distribution and power curve)



Distribution of active power output of wind farms (real data)



IV. Distribution of Voltage

Cumulative Distribution Function of voltage can be computed through Cumulative Distribution function of power and supposing a relationship between active and reactive power.

For example, if power factor is fixed, Q = k P, where k = tan(φ)

$$C2 = \sqrt{4\,(1+k^2)\,U^2\,(Uo^2 - U^2\,Abs[A]^2)\,Abs[B]^2 - U^4\,(B\,(i+k)\,Conjugate[A] - A\,(-i+k)\,Conjugate[B])^2}$$

$$C3 = U^2\,((B - i\,B\,k)\,Conjugate[A] + A\,(1+i\,k)\,Conjugate[B])$$

Active power corresponding to a certain voltage

$$P1 = \frac{C3 - C2}{2\,(1+k^2)\,Abs[B]^2};\quad P2 = \frac{C2 + C3}{2\,(1+k^2)\,Abs[B]^2};$$

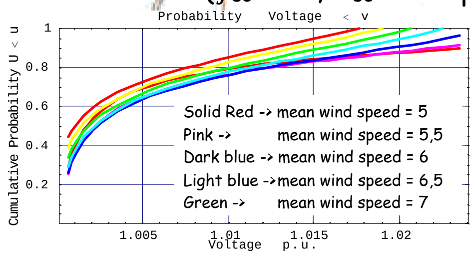
$$CDF[U < u] = 1 + CDF[ActivePower < P1] - CDF[ActivePower < P2];$$

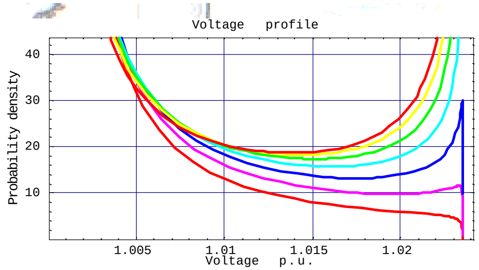
In the analyzed cases, power and voltage are linearly related by short circuit impedance:

$$U \approx Uo + \frac{P\,R + Q\,X}{Uo}$$

Therefore, voltage and power distribution have almost the same shape (minor influence in voltage when k = $-R_{sc} / X_{sc}$).

Study case: Simple impedance connecting the farm to the network (j_{sc}=60°, Z_{sc}=1/20 p.u.)





Note: Near collapse, voltage decreases quickly and this equation is no longer valid, but this is not the case of wind farms in Spain (in normal operation), due to the limit:

$$P_{short\ circuit} > 20\ P_{wind\ farm}$$

V. Availability of Reactive Power Regulation

Reactive power can be controlled in a range, depending on the wind. Some turbines can generate reactive power even when they are still. The ability to generate reactive power is best characterized using the statistical distribution of the feasible reactive output. The objective of the control can be stabilize voltage or diminish losses.

The availability must be computed taking into account if reactive generation is possible at stand-by, possible voltage limit violations.

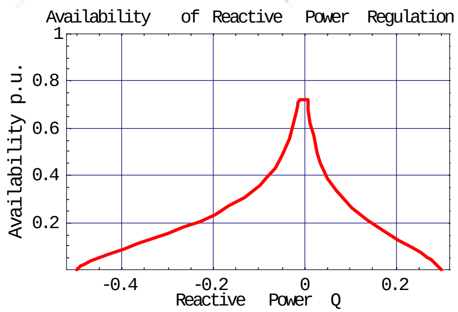
$$F_{Qmax}[Q_{turbine} \le q] = F_P[P_{mín} \le p < P_{máx}] = F_P[p < P_{máx}] - F_P[p \le P_{mín}]$$

- Reactive limited by maximum capacitive and inductive power factor.

$$Pind = Min[Pcutout, Max[Pcutin, -Q / kind]]$$

$$Pcap = Min[Pcutout, Max[Pcutin, Q / kcap]]$$

$$CDF[Q < q] = If[Q > 0, 1 - CDF[P < Pcap], 1 - CDF[P < Pind]]$$

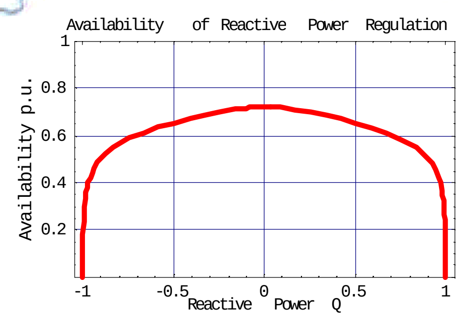


Farm with $k_{max\ cap}$ = 0,3 = tan($\varphi_{max\ cap}$); $k_{max\ ind}$ = 0,5 = tan($\varphi_{max\ ind}$)

- Reactive limited by apparent power.

$$Min[P_{cutout}, Max[P_{cutin}, \sqrt{S_n^2 - Q^2}]]$$

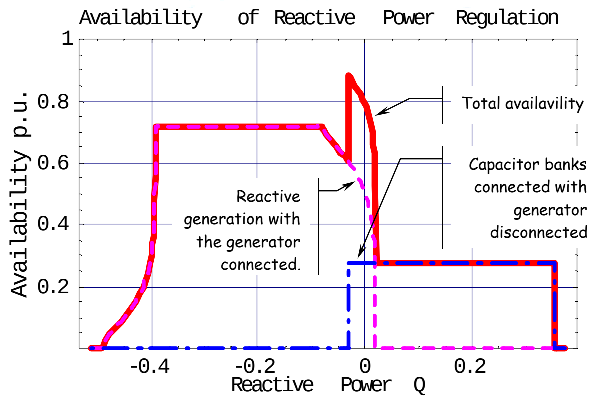
$$CDF[Q < q] = CDF[P < P1] - CDF[W < Wcutin]$$



- Induction generator with capacitor banks

Reactive power in a farm with induction generators follow approximately a quadratic relationship.

$$Q \approx Q_{cond} - Q_0 - Q_{\mu gen} - b\,S - cS^2$$



References

[1] UNE-EN 50160 "Características de la tensión suministrada por las redes generales de distribución"

[2] J. Mur, J. Sallán, A. A. Bayod, "Statistical model of wind farms for power flow", International Conference On Renewable Energies And Power Quality (ICREPQ'03), Vigo 2003.

[3] A. E. Feijoo, J. Cidrás, J.L.G. Dórenlas, "Wind speed simulation in wind farms for steady-state security assessment of electrical power systems", IEEE Trans, on Energy Conv., Vol. 14, No 4, Dec. 1999, pp 1582-1588.

[4] C.L. Masters, J. Mutale, G. Strbac, S. Curcic and N. Jenkins "Statistical evalualtion of voltages in distribution systems with embedded wind generation", IEE Proc.-Gener. Transm. Distrib. Vol. 147, N° 4, July 2000, pp. 207-212.

[5] R. Allan, R. Billinton, "Probabilistic Assessment of Power Systems", Proceedings of the IEEE, Vol. 88, No 2, February 2000, pp 140-162.