Discussion of "Modeling of Wind Farms in the Load Flow Analysis"

C. R. Fuerte-Esquivel, J. H. Tovar-Hernández, G. Gutierrez-Alcaraz, and F. Cisneros-Torres

These discussors would like to congratulate the authors on their interesting and timely paper[1] on steady-state wind farm models suitable to load flow analysis.

The discussors would like the authors to clarify and comment on the following issues.

The methods used to take into account nonconventional power plant components, e.g., FACTS devices, HVDC links and/or wind farms, in a load flow formulation can be broadly classified into two main categories: sequential and simultaneous solution method. The latter combines simultaneously the state variables corresponding to those components with the nodal voltage magnitudes and angles of the network in a single frame-of-reference for a unified, iterative solution through a Newton–Raphson technique. Assuming adequate initial conditions, the method retains Newton's quadratic convergence.

In the PQ model, an option is to consider the reactive power as a function of the nodal voltage magnitude as given by eqs. (1) or (3) of the paper. Hence, the specified reactive power is updated in each iteration. Is this updating carrying out in a *sequential or unified way*?

In the RX model, the nodal voltage magnitudes and angles are the only state variables which are calculated by a load flow analysis, whilst a sub-problem is formulated for updating the slip of the induction machine. The sequential iterative approach used is rather attractive because it is straightforward to implement in existing Newton–Raphson programs but caution has to be exercised because it will yield no quadratic convergence, as reported in [1], [2], and in some cases, divergence cannot be ruled out. Have the authors experimented these kind of problems with their suggested model and implementation?

We believe that the RX model can be solved in a unified way based on paper's eq. (7). In this case, the load flow algorithm must be reformulated to include the mismatch equation ΔP_m in the algorithm. The final unified load flow formulation is,

$$\begin{bmatrix} \Delta P \\ \\ \Delta Q \\ \\ \Delta P_m \end{bmatrix} = \begin{bmatrix} \left[\dfrac{\partial P}{\partial \theta}\right] & \left[\dfrac{\partial P}{\partial V} V\right] & \left[\dfrac{\partial P}{\partial s}\right] \\ \left[\dfrac{\partial Q}{\partial \theta}\right] & \left[\dfrac{\partial Q}{\partial V} V\right] & \left[\dfrac{\partial Q}{\partial s}\right] \\ \left[\dfrac{\partial P_m}{\partial \theta}\right] & \left[\dfrac{\partial P_m}{\partial V} V\right] & \left\{\dfrac{\partial P_m}{\partial s}\right\} \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \\ \Delta V / V \\ \\ \Delta s \end{bmatrix}. \quad (1)$$

It must be noted that $\{\partial P_{km}^{X} / \partial s\}$ is a diagonal matrix whose order equals the number of wind farms in the network. Their elements are given by paper's eq. (8). ΔP_m is the wind farm power mismatch vector whose elements are the difference between the mechanical power and the power taken out from the wind. Finally, $\Delta s = s^{i+1} + s^i$ is the vector of incremental changes in inductor machine's slip. Your comments on this issue would be appreciated.

In the paper, a load flow analysis is carried out in a two buses system. Have the authors tested their models and suggested methodology in larger systems?

According to the results presented in Section IV, both proposed models give a similar results. Comparing these models each other, the PQ is simpler to implement and computationally more efficient. Bearing this in mind, the PQ model could be more attractive to be implemented in a load flow program. Have you found cases where the results given by this model differs significantly to those given by the RX model? If positive, what kind of operative conditions can be attributed these differences to?

Could the authors explain the guidelines to choose the probability distribution, i.e., Weibull or Rayleigh Distribution, associated to the wind speed, and their impact on the final load flow results.

In Fig. 2, a comparison of the reactive power profile, as a function of the wind speed, is presented for the proposed mathematical models. However, they are not compared with experimental measurements in order to validate them. Could the authors provide this comparison?

References

[1] C. R. Fuerte-Esquivel and E. Acha, "A Newton-type algorithm for the control of power flow in electrical power networks," *Trans. Power Systems*, vol. 12, no. 4, pp. 1474–1480, Nov. 1997.

[2] T. Smed, G. Andersson, G. B. Sheble, and L. L. Grigsby, "A new approach to ac/dc power flow," *Trans. Power Systems*, vol. 6, no. 3, pp. 1238–1244, Aug. 1991.

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[1]A. E. Feijóo and J. Cidrás, *IEEE Trans. Power Systems*, vol. 15, no. 1, pp. 110–115, February 2000.

Closure to Discussion of "Modeling of Wind Farms in the Load Flow Analysis"

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The authors wish to thank the discussors for their interest in the subject and for their suggestions, and would like to answer them:

The reactive power is updated in a sequential way, which does not involve additional problems concerning the convergence of the load flow. In our simulations the first estimation of the reactive power was always quite satisfactory, so we can say that if we take the result for the first iteration as specified reactive power, we are generally very close to the final result.

It was not a purpose of the paper[1] to improve the power flow mechanism, but to propose an alternative model for wind farms with asynchronous wind turbines, as can be deduced from the presentation of the two models. So, the set of equations (1) proposed by the discussors, similar to the sets of equations (15) given in both references [A], [B] cited by them, can be of great interest in the case of implementing such models in load flow analysis, and specially, when dealing with large electrical systems.

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[1]A. E. Feijóo and J. Cidrás, *IEEE Trans. Power Systems*, vol. 15, no. 1, pp. 110–115, February 2000.