OPTIMIZATION TOOLS ADRESSING FUZZY UNCERTAINTY AT POWER FLOWS

Eduardo M. Gouveia[1] and Paulo Moisés Costa[1,2]
[1] *School of Technology and Management, Polytechnic Institute of Viseu, Campus Poliécnico de Repeses, Viseu, Portugal*
[2] *INESC Porto, Porto, Portugal*

Keywords: Power Flow, Fuzzy, Symmetric, Optimization.

Abstract: Power flow studies use computational tools for the planning and operation of electrical power systems purposes. The deterministic model is the most commonly used load flow approach. In this model, the input data and the results are crisp values. Therefore, to account for uncertainties, the most common approach used is the definition of scenarios, which are characterized by crisp values. This is an impractical way to solve the problem of the uncertainty in the data. A more practical way to lead with the uncertainties is the use of probabilistic power flows. On such approach, the uncertainties are modelled through the use of probability density functions (pdf). However, that approach may be inappropriate, namely when there is no available historical data in order to construct the pdf. On such cases, the fuzzy power flows (FPF) is an interesting alternative. In this paper, a methodology named Symmetric Fuzzy Power Flow is used. That methodology uses optimization models to solve power flow problems considering the uncertainty treated as fuzzy numbers. A comparison between the proposed methodology and the classic ones is also provided.

1 INTRODUCTION

Power flows is one of the most used tools to support the planning and operation activities of the transmission network. There are two main classes of power flows considering uncertainty, the probabilistic power flow (PPF) (Borkowska, 1974) and the fuzzy power flow (FPF) (Miranda and Matos, 1989; Saraiva et al., 1991). In the PPF the variables (generation and load) are considered as random variables with probabilistic distributions (pdf). The results of PPF are also in the form of pdf, namely the voltages and power flows. This model presupposes the existence of historical data for the input variables that can guarantee the construction of a statistical distribution. However, the historical data may not be available, namely when we are leading with emergent concepts as the generation at LV networks and the electric mobility. Therefore, new tools are needed in order to solve the problem resulting from the inexistence of historical data. The FPF is an interesting alternative on such context, once this approach treats the uncertainty without requiring the existence of statistical distributions for the input data. The FPF, allows describe mathematically qualitative statements or vague information by using fuzzy models. The classic formulations of FPF present some limitations that may distort the results, namely: i) existence of a slack bus (which aggregates all uncertainty that comes from the all other buses of the transmission; ii) linearization models used at the computation. Saraiva el al, 2004 presented a model that includes data correlation. An inclusion of a corrective procedure for the slack bus is purposed by (Saraiva et al, 1991), which consists in defining limits for generation. In this situation, the slack bus still being different from the others buses since continues to receive the uncertainty from them.

In this paper a symmetrical model (SFPF) purposed by Matos and Gouveia (2008) is used in order to overcome some of the limitations of the preceding models. In fact, the slack bus is treated as all other buses and non linearization procedures are adopted. The proposed model uses optimization problems to obtain symmetrical solutions for the power flow problem (regarding linearized and the complete model). The main purpose of the paper is to analyse the results of the SFPF and compare those results with the ones of classic versions of the FPF.

M. Gouveia E. and Moisés Costa P..
OPTIMIZATION TOOLS ADRESSING FUZZY UNCERTAINTY AT POWER FLOWS.
DOI: 10.5220/0003760502190222
In *Proceedings of the 1st International Conference on Operations Research and Enterprise Systems* (ICORES-2012), pages 219-222
ISBN: 978-989-8425-97-3

The paper is organized in the following way: Section 2 - concepts of FPF and SFPF are reviewed; section 3 - three case studies are presented (the IEEE test grids with 14, 24 and 118 buses are used); section 4 - some conclusions are extracted.

2 FUZZY POWER FLOW

There are three types of fuzzy numbers generally used in FPF to describe input data at fuzzy power flow models: rectangular, triangular and trapezoidal. Triangular and rectangular fuzzy numbers are particular cases of trapezoidal fuzzy numbers. Triangular and rectangular fuzzy numbers are particular cases of trapezoidal fuzzy numbers. For instance, a trapezoidal fuzzy number (Figure 1) can be described by the set of equations (1).

$$p_F(x) = \begin{cases} 0, & if \;\; x \le a_1 \\ \dfrac{x-a_1}{a_2-a_1}, if & a_1 \le x \le a_2 \\ 1, & if \;\; a_2 \le x \le a_3 \\ \dfrac{a_4-x}{a_4-a_3}, if & a_3 \le x \le a_4 \\ 0, & if \;\; x \ge a_4 \end{cases} \tag{1}$$

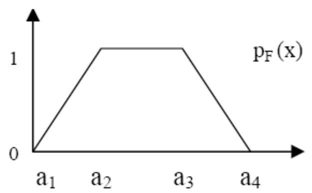

Figure 1: Trapezoidal Fuzzy Number.

2.1 Classical Fuzzy Power Flow

The first formulation of Fuzzy Power Flow was based on a DC model for the power system. In this model if $\tilde{P}$ is the fuzzy vector of injected power in the nodes. an approximation of the arguments, $\tilde{\theta}$ and branches' flows $\tilde{P}_B$, is obtained using:

$$\tilde{P}_B = A.\tilde{P} \tag{2}$$

$$\tilde{\theta} = B^{-1}.\tilde{P} \tag{3}$$

At these model, crisp matrices A and B corresponds to the sensitivity and admittance matrices of the DC power flow.

The AC model of FPF was proposed by Miranda et al (1990). This model uses a first-order Taylor series expansion of the power flow equations. To obtain the fuzzy voltages and angles a deterministic AC power flow for the central values of the fuzzy data is solved, using the Newton-Raphson algorithm. Then, the variations around this operating point are calculated by using the Jacobian of the last iteration and fuzzy arithmetic's. For other variables like the power flows, a similar strategy of linearization is used. More details about this model can be found in Miranda el al (1990).

2.2 Symmetric Fuzzy Power Flow

The SFPF consists of solve for each α level of the possibility distribution (Figure 1), optimization problems in order to obtain the maximum and minimum value that fuzzy variable may take, for all the possible values (with degree of membership greater than or equal to α). Note that no slack bus is defined since fuzzy injections for input data are considered for all the buses of the transmission network. For the DC model of SFPF (Matos and Gouveia, 2008) we must solve linear programming problems (for each α level) to obtain the maximum value of the power flow in branch k. At this model (4), "Ref" means the reference bus and $\tilde{P}_i(\alpha)$ is the α-level interval of the nodal active injected power. If is desired the injected power at a specific bus, the objective function will be $\tilde{P}_i(\alpha)$.

$$\begin{aligned} \max \quad & \tilde{P}_k(\alpha) = \sum_{i \ne Ref} A_{ki}.P_i \\ st: \quad & P_i \in \tilde{P}_i(\alpha) \qquad \qquad all \; buses \; i \\ & \sum_i P_i = 0 \end{aligned} \tag{4}$$

Gouveia and Matos (2008) also extend the SFPF to the AC case. Now the standard equations of the AC power flow problem are included as constraints, along with the α-limits for each fuzzy variable. The maximum α-level value for each fuzzy variable $\tilde{Z}$ will be the result of following optimization problem (5). The analysis for the minimum is analogous. Variable Z may be any of the voltages in PQ buses, any of the voltage angles, any of the power flows P_{ik}, Q_{ik} or S_{ik} or the power losses in a branch or in the entire system. In (5), G_{ik} and B_{ik} are, respectively, the real and imaginary components of the admittance matrix elements, $\tilde{P}_i(\alpha)$ is the α-level interval of the active injected power $\tilde{P}_i$ and $\tilde{Q}_i(\alpha)$ is the α-level interval of the reactive injected power $\tilde{Q}_i$

$$
\begin{aligned}
\max \quad & \tilde{Z}(\alpha) \\
st: \quad & P_i = V_i \sum_{k=1}^{n} V_k (G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) && all\,buses\, i \\
& Q_i = V_i \sum_{k=1}^{n} V_k (G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik}) && all\,buses\, i \\
& P_i \in \tilde{P}_i(\alpha) && all\,buses\, i \\
& Q_i \in \tilde{Q}_i(\alpha) && all\,buses\, i \\
& V_i = V_i^{SP} && PV\,buses\,and\,Ref \\
& \theta_{\mathrm{Ref}} = 0
\end{aligned}
\tag{5}
$$

3 CASE STUDY

In this section we will perform the exercise of comparing the results obtained from SFPF with the ones available at the literature obtained by the classical FPF.

3.1 Linear Models of FPF

Three different models were used to solve the power flow problem (DC model) for the 24 Bus, 38 branches IEEE test system: the first model of FPF created by Miranda and Matos (1989); the model with correction procedures which consider generations limits to the slack bus (Saraiva et al, 1991); and the SFPF (Gouveia and Matos, 2008). Those models are indentified in the following paragraphs and figures as “First”, “Cons” and “Sym”. We will consider the uncertainty modelled as trapezoidal fuzzy numbers (triangular or rectangular fuzzy numbers also could be used). The values indicated in Table I will be considered the central values of the trapezoidal fuzzy numbers. For these data the characteristic points are assumed to be as shown at Table 2. For instance, applying this information to node 9, we’ll get a fuzzy load of (Figure 2). A base power of 500 MW is used and bus and branch data are available at (Saraiva et al, 1991); The bus 1 is the reference bus.

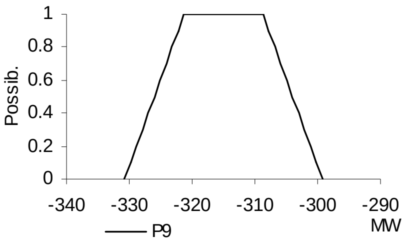

Figure 2: Fuzzy load.

The voltages for PV buses 1, 2 and 7 will be 1.075 pu and for the others 1.025 pu. At the reference bus, depending on the model we will have different situations: “First”- no fuzzy description for generation is considered; “Cons” – were considered generation limits of [0-800 MW]; “Sym” is defined a fuzzy generation. In this fuzzy trapezoidal number the extreme points (a_1, a_2, a_3, a_4) will be (0, 500, 600, 800) MW. After solving the optimization problem (4) twice (max and min) for α cuts between 0 and 1 for all branches with large branch limitations we obtain the ranges for the $P_{i\text{-}k}$ power flows. For instance for branch 1-2 (Table 2, Figure 3) the main points of interest of the possibility distribution are referred (α=0_-, α=0.7_-, α=1_-, α=1_+, α=0_+). Figure 4 show the same kind of results for branch 5-10. As can be verified formulations “First” and “Const” provides results with larger ranges of uncertainty for power flows since slack bus concentrates all uncertainty which comes from all other buses.

Table 1: Characteristic points of fuzzy data.

Bus	characteristic points for generation			
1-13, 14-24	0.95	0.98	1.02	1.05
13	1.00	1.00	1.00	1.00
	characteristic points for loads			
1-5, 7-19, 21-24	0.95	0.98	1.02	1.05
6, 20	1.00	1.00	1.00	1.00

Table 2: Power flow fuzzy distributions, branch 1-2 (MW).

Branch	0	0.7	1	1	0
1-2 (First)	-68.0	11.2	45.1	196.1	309.2
1-2 (Const)	-68.0	11.2	45.1	196.1	245.3
1-2 (Sym)	-68.0	18.9	85.2	147.2	245.3

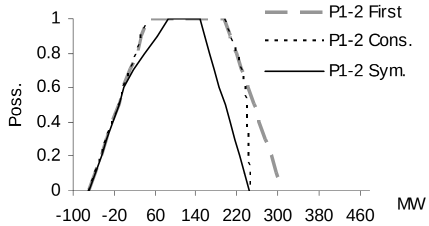

Figure 3: Fuzzy load flow in branch 1-2.

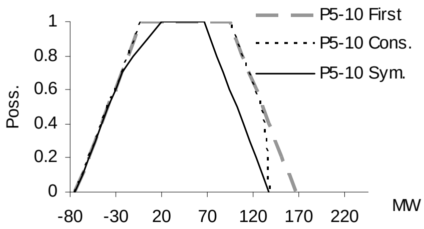

Figure 4: Fuzzy load flow in branch 5-10.

3.2 Complete Models of FPF

Now we will perform the exercise of comparing AC SFPF with classical AC FPF models. Considering the model based on FPF, the boundary load flow (BLF) (Dimitrovski and Tomsovic, 2004) we will use the IEEE 14 and 118 test systems. Data of these networks can be seen at (http://www.ee.washington .edu/research/pstca/. The BLF uses an interactive procedure in order to enhance the results accuracy in cases of considerable non linearity due to large uncertainty in input data. The characteristic points for IEEE 14 bus test system at α=0 are assumed to be 0.0 and 2.0 of the central values (rectangular fuzzy numbers). Performing the comparison with the exact values calculated with the SFPF shows that some "artificially uncertainty" is still present in the BLF results. Table 3 shows results for voltage magnitudes. The same kinds of results (not shown) were also obtained for active power flows. Using the 118 bus test system also Gouveia and Matos (2008) found differences between the FPF, BLF (that falls under same philosophy of FPF) and SFPF. Those differences are exposed for some of the variables of this network (Table 4). Now the characteristic points for α=0 are assumed to be 0.6 and 1.4 of the central values.

Table 3: Voltage values (pu) IEEE 14 bus test system.

α=0, [0.0-2.0]				
Bus	BLF		SFPF AC	
4	0.978	1.045	0.992	1.045
5	0.981	1.042	0.996	1.042
7	1.024	1.089	1.051	1.088
9	1.001	1.101	1.028	1.101
10	0.997	1.096	1.020	1.096
11	1.025	1.084	1.038	1.083
12	1.036	1.072	1.039	1.072
13	1.023	1.074	1.028	1.074
14	0.972	1.089	0.992	1.088

Table 4: Voltage and Power Flow Values (p.u.) for some variables of IEEE 118 test system.

Var.	FPF		BLF		Sym. FPF	
V44	0.94	1.03	0.87	1.01	0.96	1.01
P68-69	-17.44	14.92	-21.10	13.27	-3.74	1.39
Q68-69	0.39	1.86	0.84	9.25	1.07	1.33

4 CONCLUSIONS

The use of SFPF doesn't consider a slack bus or linearization procedures as happens at the traditional formulation of FPF. At FPF the use of these simplifications have as a consequence a distortion of the results mainly due the influence of the slack bus. While in the deterministic power flow formulations the slack bus only compensate the uncertainty in loss estimation, at classical FPF compensates the uncertainty that comes from all other buses. Adding to this the linearization procedures used, results shown "excessive" uncertainty as shown in this paper at the several IEEE networks tested. Finally, the SFPF models have the drawback of requiring solving a great number of optimization problems but are completely symmetric regarding the buses. This is not a real problem since SFPF are addicted to long-term planning studies. However justify future work in order to improve simulation times.

REFERENCES

Borkowska, B., 1974. Probabilistic load flow. *IEEE Transactions on PAS* 23 (3), 752– 759.

Dimitrovski A, Tomsovic K, 2004. Boundary Load Flow Solutions, *IEEE Trans. Power Systems*, vol. 19, no.1, February 2004, pp 348-355.

Gouveia E M, Matos M A, 2008 "Symmetric AC Fuzzy Power Flow Model", European Journal of Operational Research, DOI: 10.1016/j.ejor.2007.12.044"

Matos M A, Gouveia E M, 2008. Fuzzy Power Flow Revisited, Power Systems, *IEEE Transactions on*, Volume 23, Issue 1, Page(s):213 – 218, February 2008

Miranda, V., Matos, M. A., 1989. Distribution system planning with fuzzy models and techniques. In: *Proceedings of the CIRED 89*, Brighton, pp. 472–476

Miranda, V., Matos, M. A., Saraiva, J. T., 1990. Fuzzy load flow - new algorithms incorporating uncertain generation and load representation. *In: Proceedings of the 10th PSCC*, London, pp. 621–627

Saraiva, J T, Fonseca N, Matos M A, 2004. Fuzzy Power Flow – An AC Model Addressing Correlated Data, in: *Proc PMAPS'04*, Iowa, September 2004, pp 519-524.

Saraiva, J. T., Miranda, V., Matos, M. A., 1991. Generation and load uncertainties incorporated in load flow studies. In: *Proceedings of the MELECON 91*, 424 Ljubljana, pp. 1339-1342