DETERMINISTIC VERSUS PROBABILISTIC APPROACHES TO SELF-HEALING IN SMART GRID

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ABSTRACT

This paper presents a comparison between deterministic and probabilistic approaches to support decision making process for self-healing in smart grid, aiming to improve reliability indexes. Probabilistic load flow (PLF) considers inputs as probability density functions (PDFs) or cumulative distribution functions (CDFs), and therefore may give a more reliable power analysis. Three methodologies, namely deterministic load flow (backward/forward sweep), probabilistic load flow through Monte Carlo simulation and probabilistic load flow through Herman-Beta method were tested with real data of two distribution feeders located in Rio de Janeiro, Brazil. The simulations show that probabilistic approaches are able to provide valuable information to a more reliable decision making process for service restoration.

INTRODUCTION

As the generation (including dispersed and renewable energy sources - RES) and electric loads tend to have a variable dynamic behaviour, another approaches beyond deterministic power flow becomes necessary to fully evaluate grid performance.

Beyond the aforementioned behaviour, uncertainties in the power systems may occur due to errors in measurements, uncertainty in load distribution between phases, imprecision in the calculation or prediction of demand levels, imprecision in system parameters such as lines resistance and unscheduled outage [1][2].

As the smart grid becomes a reality, it becomes even more important to have a trustworthy analysis of the power systems states and flows. The smart grid performs the integration of information and communications technology with the power system, and therefore enables better coordination and interaction between different market players such as generators, grid-operators, customers and others, causing a maximization of efficiency, reliability and stability of the system [3].

One of the goals of the smart grid is to achieve self-healing functionalities, i.e. a grid that attempts to “heal” itself in the sense of recovering from faults and regaining normative performance levels independently; the concept derives from the manner in which a biological system heals a wound [4].

This improvement in the operation of the power systems can help utilities to assure power quality (e.g. voltage profile) and keep indexes as SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index) as low as possible, avoiding undesirable costs and a reliable power distribution.

The subject addressed in this paper is the comparison between deterministic and probabilistic approaches to support the decision making process for self-healing in smart grid. Probabilistic load flow (PLF) considers inputs as probability density functions (PDFs) or cumulative distribution functions (CDFs), and therefore may give a more reliable power analysis.

The studies and methodology presented in this paper were developed within the Smart Grid R&D project of LIGHT SESA, a Brazilian power utility located in Rio de Janeiro.

PROBABILISTIC POWER FLOW

Deterministic load flow (DLF) is traditionally used to support decision making on the planning and operation of power systems, with fixed values parameters as input. DLF disregards uncertainties on the power system as failure rates or intermittence on power generation, network reconfiguration and load variations, requiring a new computation for any variation on input values [5]. For distribution systems the most commonly used methods are either variants of Newton methods or backward-forward sweep [5].

Probabilistic load flow (PLF) was first proposed in 1974 by Borkowska [1] and has been applied to the design of low voltage feeders [7], adjustment of voltage and reactive power control devices [8], assessing the effects of distributed generation and voltage mitigation equipment [9] as well as other areas. PLF requires PDFs or CDFs as input parameters to obtain systems states and power flows in terms of PDFs or CDFs, allowing the analysis of the results within a confidence range. PLF can be solved numerically (e.g. Monte Carlo method), analytically (e.g. Herman-Beta method) or in a combination of both.

The Monte Carlo Method consists of a simulation technique for assessing the behaviour of a statistic in random variables by the empirical process of considering lots of random samples. The main drawback about this technique is the large number of simulations needed, but, due to its high accuracy, it is usually used as a reference to compare other PLFs [5][10].

The Herman-Beta method, proposed in [7], incorporates a probabilistic approach that uses the Beta probability distribution of loads. This method is the South African standard for planning and design of distribution networks [11]. Although its accuracy is reduced due to approximated models, all expressions used in the method are linear and it can be easily programmed into spreadsheets.

PROBABILISTIC METHODOLOGY FOR SELF-HEALING

On this paper both aforementioned probabilistic methods were tested and compared to a deterministic approach, aiming to support self-healing decision making in smart grid.
In the proposed methodology, a fault will be considered between two subsequent reclosers of a set of distribution feeders, for which an optimal configuration for the service restoration will be proposed.
To ensure that the voltage profile obtained through PLF is within an imposed range set by Brazilian standards [12] (0.93 p.u. ≤ Voltage ≤ 1.05 p.u.), a confidence level was defined. Considering the normal distribution, a confidence level of 95.45% will assure that the expected value ±2 standard deviations will not trespass any limits.
To calculate the objective function for the probabilistic approaches, the worst case scenario considering the set confidence level was used. In the DLF simulations, through the backward/forward sweep method, an analysis of the normative voltage performance is also undertaken.
The switching solutions within an acceptable voltage profile were ranked, aiming to reduce SAIDI and SAIFI penalty values. According to Brazilian standards, power utilities have to pay a financial compensation to customers when they trespass a certain level of these index. This compensation is made through a coefficient that varies according to the voltage level of the customer's connection point (LV and MV), as used in the following objective function (OF) to be minimized:

$$OF = n_{LV} \times load_{LV} \times k_{LV} + n_{MV} \times load_{MV} \times k_{MV}$$

where n_{LV} and n_{MV} are respectively the amount of disconnected customers in the low and medium voltage, k_{LV} is 15 and k_{MV} is 20 according to Brazilian standards [12]. The variables $load_{LV}$ and $load_{MV}$ represent the amount of load not supplied for the low and medium voltage, respectively, in kVA. For the probabilistic case the load not supplied used was the worst case scenario, i.e. the maximum amount of load not supplied considering the confidence range established.
In the PLF through Monte Carlo method, all input samples were solved using the DLF (5000 simulations). The samples were defined following the normal distribution, as presented in [10].
The PLF through Herman Beta method was implemented as presented in [11]. This method does not deal directly with branched feeders, thus firstly the main feeder section was considered, adding the total number of loads to the connection points. Afterwards simulations for each branch was run (considering the results already obtained), achieving the normal curve as result for each system state and flows.

SIMULATION AND RESULTS

Simulations were run using real data of two distribution feeders in Rio de Janeiro, Brazil, under the concession of Light SESA. Power flows were calculated for the MV (Medium Voltage, 13.0 kV), with loads connected both to the MV and LV (Low Voltage). These two feeders have a two and half recloser's configuration to allow the desired self-healing functionalities.
Operational data regarding the loads were used for the DLF and for the first moment (mean) of the input load data of the PDFs. A standard deviation of 10% of the mean was considered. In a field application of the proposed method for self-healing, the mean and standard deviation will be obtained through smart metering. The confidence level set for the analysis of voltage profile in the PLF was 95.45% (i.e. ±2 standard deviations).
All simulations were run on Matlab® environment, with an Intel i7 2.80 GHz, 6GB RAM, Windows 7 Professional.
Fig. 1 presents georeferenced post-fault scenario of the selected feeders considering a fault between two reclosers on feeder 1 (coming from power substation 1), not taking into account protection functionalities.

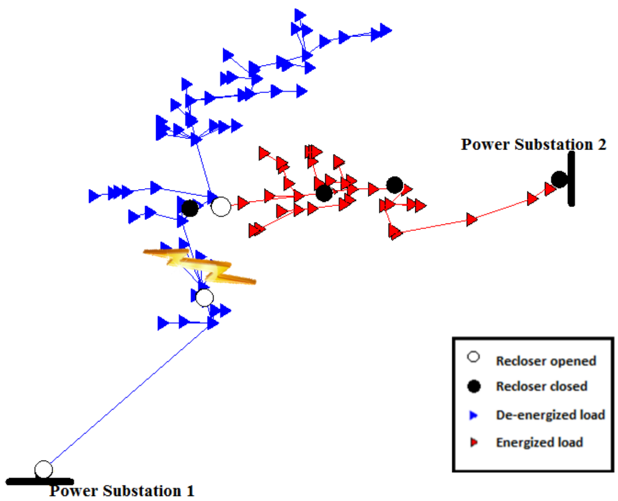

Fig. 1 – Post-fault on the distribution feeders

Feeder 1 has a total length of 7.42 km and total nominal transformer capacity of 8005 kVA (being 825 kVA connected to the MV). Feeder number 2 is 4.30 km length and its total nominal transformer capacity is 5100 kVA (being 837.5 kVA connected to the MV).
Fig.2 presents georeferenced data on the optimal switching configuration for the DLF, while Fig. 3 presents the configuration for PLF-Monte Carlo and PLF-Herman Beta. Table 1 shows a comparison between all simulations made.

Table 1 – Comparison of methods on their optimal switching configuration

Method	OF	Computing time [s]
DLF	1.300e+10	2.828
PLF- Monte Carlo	1.0270e+11	8305.196
PLF- Herman Beta	4.8209e+11	1.534

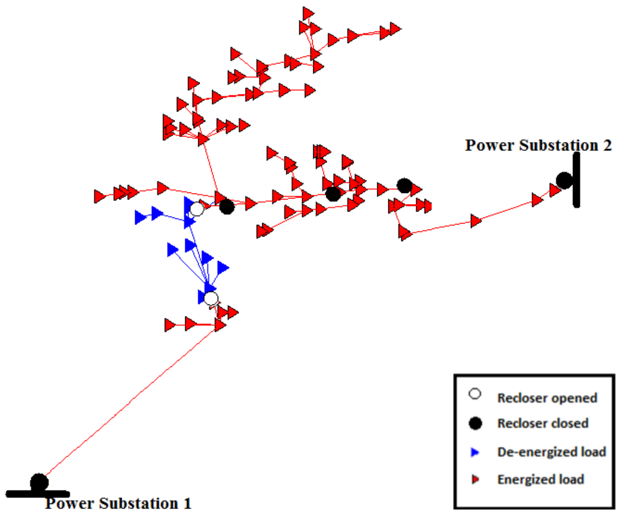

Fig. 2 – Optimal switching (DLF and PLF-Monte Carlo)

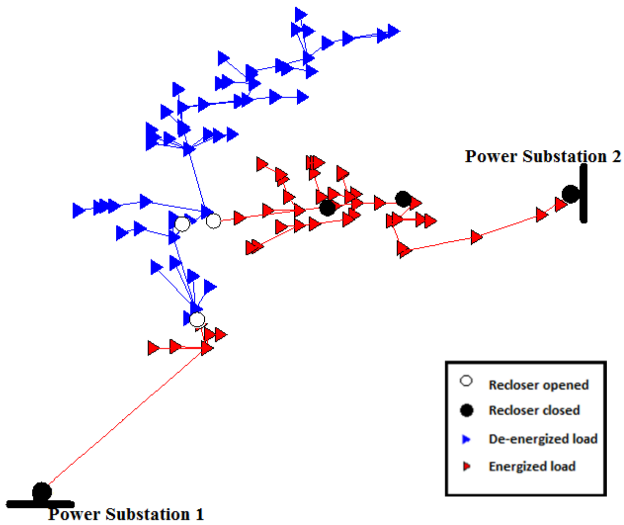

Fig. 3 – Optimal Switching (PLF-Herman Beta)

Table 2 – Comparison of methods on the optimal switching (Fig. 2's topology)

Method	Lowest voltage value on feeder [p.u.]
DLF	0.955
PLF-Monte Carlo	0.9547
PLF- Herman Beta	0.896

Self-Healing through DLF and PLF-Monte Carlo restored more loads and achieved a lower score on the objective function than PLF-Herman Beta.

As shown in Table 2, the lowest voltage obtained in the DLF did not trespass any limits, but, if the loads' behaviors vary normative performance would not be guaranteed without further statistical analysis. If loads vary within the expected normal curve, the configuration through both PLF methods will be able to operate within voltage normative limits, with a confidence of at least 95.45%. Considering the confidence level set, the configuration presented in Fig. 2 will not be obtained through PLF-Herman Beta, but if the level was diminished to, at least, 63.6%, this configuration would be accepted.

Voltage profiles of the optimal switching configuration of PLF approaches are presented in Fig. 4 and Fig. 5, with the cumulated impedance of each bus in x-axis. This graph intention is to enable a visualization of the voltage profile, so that the reader may relate to the georeferenced data.

In PLF-Monte Carlo the voltage confidence (± 2 standard deviations) in all buses are somewhat similar. With PLF-Herman Beta buses that have large branches connected to it, normally shows a bigger voltage range (cumulated uncertainties). Monte Carlo therefore presents a more trustworthy and refined result, but when compared to the Herman-Beta method, the computational time needed for such simulations are 5,414 times larger.

The results showed that probabilistic approaches are more reliable to self-healing in smart grid, because of the confidence level intrinsic to the methods. PLF-Monte Carlo obtained better results, but its applicability to the operation of distribution feeders is questionable due to the computational time needed, taking into account that in Brazil SAIDI and SAIFI indexes have a tolerance of three minutes.

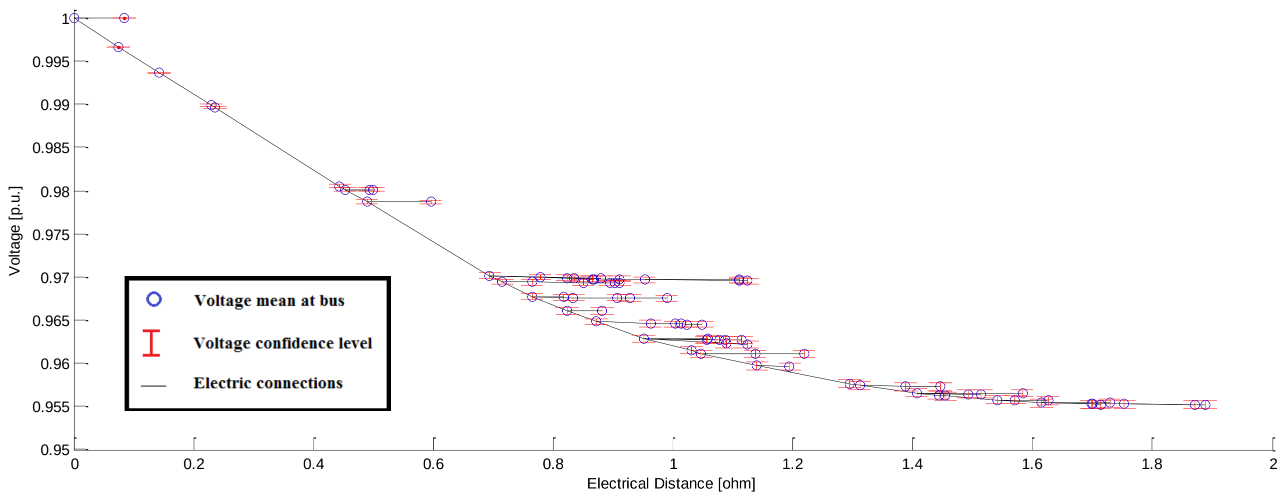

Fig. 4 – Voltage level on feeder 2 –PLF-Monte Carlo

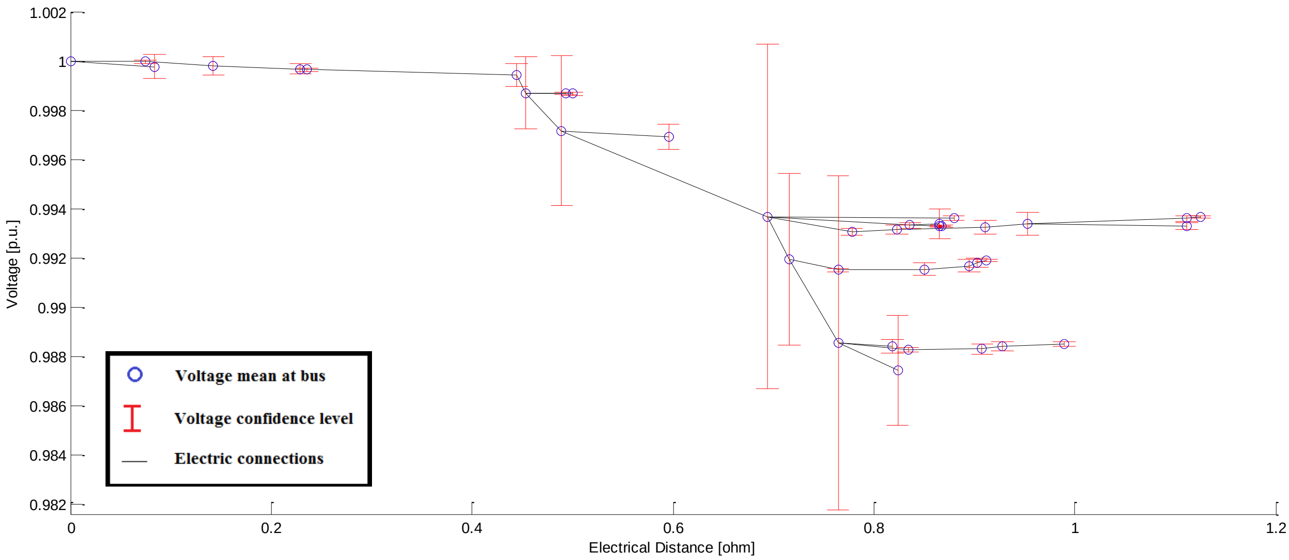

Fig. 5 – Voltage level on feeder 2 – PLF-Herman Beta

Despite the switching proposed by PLF-Herman Beta lead to a worst switching scenario, the use of PLF-Monte Carlo in the operation would certainly exceed the tolerance of three minutes, and an analysis using only the deterministic approach would lead to a riskier scenario.

CONCLUSIONS

The results shown that probabilistic approaches are able to provide valuable information to the decision making process for self-healing in smart grids. Considering that load and dispersed generation values can change very rapidly, purely deterministic approaches should be used with caution.

Both probabilistic approaches tested have their pros and cons. Monte Carlo showed itself more accurate but Herman-Beta was more suitable for a fast decision making. In future works new techniques for probabilistic load flow will be tested, aiming to obtain accurate results with suitable computing time.

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