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A Review on Optimal Power Flow Solutions under Variable Load

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ABSTRACT: This paper reviews the optimal power flow solutions under variable load conditions. In this article we review the recent trend towards non-deterministic (random) search techniques and hybrid methods for OPF and give the review conclusions. These methods have become popular because they have a theoretical advantage over the deterministic methods with respect to handling of non convexity, dynamics, and discrete variables. Present commercial OPF programs can solve very large and complex power systems optimization problems in a relatively less time. In recent years many different solution methods have been suggested to solve OPF problems. The review contributes a comprehensive discussion of specific optimization techniques that can be applied to OPF Solution methodology.

KEYWORDS: Optimal Power Flow (OPF),Optimization techniques , Karush–Kuhn–Tucker (KKT).

I.INTRODUCTION

A progressive increase of the load and the deregulation of the electric energy Systems have added to the complexity of determining adequate solutions for the electrical power system steady state operation problem. Therefore the study of voltage collapse and Optimal Power Flow Solutions acquires a great significance and there is a need for methodologies which are able to simultaneously analyze these two aspects to indicate the behavior of power systems, being operated near the maximum loadability limit. Different methodologies were proposed to calculate the maximum loadability limit of power systems. The approach presented in [1] proposes the determination of this limit through the computation of the steady state multiple solutions. In reference [2], sensitivity relationships between the power system variables are used to calculate the critical load. The Singular Value Decomposition of the conventional Newton–Raphson Jacobian matrix was also applied [3]. The parameterization of the steady state power system equations was also used to formulate the problem of maximum loadability [4], [5]. These two last works applied the continuation method to track the load flow solution for an increasing system demand.

The OPF algorithms have been existing since sixties and have been extensively used to asses the economic aspect of power system operation. Some of these algorithms apply parametric optimization techniques, some use different versions of the Continuation method [6]–[12]. Some of these methodologies are based on the Newton OPF method [13]. Combining the different methods with the optimization algorithms can provide a strong tool for power system analysis and OPF solutions .The Interior Point (IP) algorithms which provides linear programming solutions has been used for solving nonlinear OPF problem [15]–[18] where its efficiency of finding the optimal solution and its effectiveness in handling the inequality constraints have been claimed as its main features. Some of these works proposed the use of an OPF algorithm to compute the point of maximum loadability of the power systems via nonlinear versions of Interior Points methods [17], [18]. The use of optimization algorithms for the study of heavily loaded systems allows the representation of all the operational limits and, depending on the OPF formulation, the adoption of an criterion to be optimized [14], [17], [18]. The steady state behavior of power systems working under heavy load can be studied in a better way.

A research work on a methodology that combines the Continuation method with a nonlinear version of the Interior Point algorithm can be worked upon where the first will provide a sequence of estimates for the solution of the

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Karush–Kuhn–Tucker (KKT) conditions from a base case to the point of maximum loadability. Each solution of this sequence can be determined through the OPF Interior Point algorithm. This combination may allows the optimal tracking of the load growth, even in the neighborhood of the feasibility limit, where the Newton's solver is bound to diverge due to the ill-conditioning of the Jacobian of the KKT conditions [14].

II. THE MAXIMUM LOADABILITY PROBLEM

Solving the maximum loadability problem gives the maximum real and reactive power demand that a power system is able to bear, while operating at a stable point (i.e., one which does not change considerably for small increments on the systems parameters such as load or operational limits), that respects a set of pre-defined operational limits. A steady state formulation of this problem can be made in terms of the load flow system of equations. The parameterization of the bus loads gives a modified set of power balance equations, in which the load increase direction is explicitly represented:

$$\boldsymbol{g}(\boldsymbol{x}, \epsilon) = \boldsymbol{g}(\boldsymbol{x}) + \epsilon \boldsymbol{d} \tag{1}$$

where

ε is the load parameter

$g(x)$ is the set of power flow equations and

d is the pre-specified load increase direction.

In subject to this case, the calculation of the maximum loadability of power systems will consists of solving (1) to find the complex bus voltages corresponding to the maximum value of ε .For an optimally operated system the maximum loadability problem is to find the maximum value of for which problem $p(\varepsilon)$

$$\text{Min } f(x) \tag{2}$$

subject to

$$g(x, \varepsilon) = 0 \tag{3}$$

$$h(x, \varepsilon) = 0 \tag{4}$$

has feasible solutions

the vector of decision variables $P(\varepsilon)$, is composed of the active power generations, bus voltage magnitudes and angles, transformer tap settings and phase shifter angles. The objective function, f(x) , can represent the power generation cost, the transmission losses, the voltage deviation from a pre-specified voltage level or any combination of these three indices. The set of inequality constraints, h(x, ε), which comprises the upper and lower limits of the decision variables and functional inequalities such as the limits on the generated reactive power and line flows, can also be dependent on the bus loads:

$$h(x, \varepsilon) = h(x) + \varepsilon d_1 \tag{5}$$

where d_1 represents a pre-specified load increase direction.

The solution $P(\varepsilon)$ can be tracked for increasing ε until the maximum loadability limit is reached. The difficulties to solve this nonlinear optimization problem are well known, and presently most of the algorithms which were successful in its resolution are based on the solution of the its pure or modified KKT conditions by linear approximations (Newton method). However, it can be shown that near the feasibility limit the Jacobian of the KKT conditions of $P(\varepsilon)$is ill-conditioned [14] which may causes an additional difficulty in the tracking of the solution of $P(\varepsilon)$up to the maximum value of ε. Thus the analysis of the OPF behavior near the maximum loadability limit must be done with algorithms which can diminish the problem of ill conditioning observed near such limit. This is the main motivation of the review and research.

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III.THE PROPOSED APPROACH

The application of the Interior Point algorithms to solve problem P*(ε)* consists basically of: a) converting the inequality constraints in equality constraints, through nonnegative slack variables; and b) adding a logarithmic barrier function to the objective function, to preserve the non negativity condition of the slack variables. The modified parameterized optimization problem PM*(ε)* is:

$$\text{Min}\, F(\boldsymbol{x}, \boldsymbol{s}) = f(\boldsymbol{x}) - \mu \sum_{i=1}^{p} \ln(\boldsymbol{s}_i) \tag{6}$$

subject to

$$g(x, \varepsilon) = 0 \tag{7}$$

$$h(x, \varepsilon) + s = 0 \tag{8}$$

where

$\mu \geq 0$ is the logarithmic barrier
$s > 0$ is the vector of slack variables
p is the number of inequality constraints

The interior point OPF model (6)–(8) is, a parameterized model with *two distinct parameters* μ and ε . The proposed methodology will consists of changing each of these parameters at a time: in the predictor step, ε will be increased so that a new load level is considered; in the corrector step, μ will be decreased so that, at the end of the corrector's iterations, the original OPF problem is solved. We are analyzing the behavior of the OPF solutions for increasing ε, while the optimal solution will be tracked for varying ε . Nevertheless, Interior Point methods can also be interpreted as a special class of parametric optimization methods [19].

IV.ADDITIONAL STUDIES

The parameterized optimization model which is a generalization of the parameterized load flow equations used for voltage collapse studies will be able to provide similar additional information regarding the behavior of the system near the collapse point. As all the conclusions will drawn with respect to an optimal operation point and the influence of the operational limits will be considered . This operational limit will bear some important consequences on the nature of the index of the maximum variation on the voltages and on some sensitivities that can be calculated with the parameterized model. When limits are considered, the optimal solution trajectories may vary continuously with ε only in those intervals where no new limit becomes active and a "break-point" will appears upon the activation of a new inequality constraint. As a consequence, indices based on the tangent vector and also some sensitivities which are a by product of the approach, are valid only for small intervals of variation of where no new limit will be reached.

V. RESULT AND CONCLUSION

The results can be obtained keeping in mind the three categories
i) Study the OPF behavior near the loadability limit;
ii) Analysis of the efficiency of the proposed methodology and
iii) Analysis of the critical bus indices and the sensitivity of the maximum load with respect to reactive power injections.

The work can be carried on to present a parameterized OPF algorithm which will be able to track the system load variation for a specific range of the load parameter ε . This algorithm is based on the continuation method an on a primal–dual interior point method. The adopted parameterization will be studied to see that it allows the resolution of

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the OPF problem for critical loading conditions, providing some insight on the behavior of power systems being optimally operated near a feasibility limit.

Sensitivity studies can be carried out using Critical variables and operational indices to obtain reactive support which allows for a pre-specified load increase.

Study can be carried on to evaluate the cost and performance concern of the power system.

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