ANALYSIS OF NUMERICAL METHODS TO INCLUDE DYNAMIC CONSTRAIN IN TSCOPF MODELS

S. Madhumitha
Research Scholar
Sunrise University
Rajasthan.

ABSTRACT

Transient Stability Constrained Optimal Power Flow (TSCOPF) models effectively solve the optimization of power system operation, including steady state and dynamic constraints. TSCOPF studies incorporate the electromechanical oscillations of synchronous machines into well-known optimal power flow models. The discretized differential equations that depict the system dynamics in the optimization model are one of the primary methods used in TSCOPF studies. This study examines the effects of the integration time step and various implicit and explicit numerical integration techniques on the solution of a TSCOPF model. The impact on power dispatch, the overall cost of generation, the precision of the computation of electromechanical oscillations between machines, and the magnitude of the optimization problem are specifically examined and the computational time.

KEYWORDS: *power system transient stability; economic dispatch; numerical integration methods; non-linear programming; optimal power flow*

INTRODUCTION

Transient Stability Constrained Optimal Power Flow (TSCOPF) models have become a popular tool for power system operation and planning during the past ten years. The optimal operating point of electric power systems is determined by the optimization problem known as TSCOPF, which takes both static and dynamic constraints into account. Recent years have seen the publication of numerous papers on the topic, and various strategies have been put forth to address the issue.

A TSCOPF model based on simultaneous discretization consists of two parts: 1) the equations representing the steady state operation of the power system and its limits of operation; and 2) the representation of the dynamics of the system during one or more incidents, together with the stability limits. Both parts are included in a single optimization model together with the objective function. One major drawback of TSCOPF problem is that the inclusion of the dynamic representation entails a considerably increase in the number of equations and variables. To evaluate the transient stability, it is necessary to represent a period of at least 2-3 seconds. The choice of the integration time step is not straightforward and plays a very important role since a small step leads to a proportional increase in the size of the optimization problem but large integration time steps can introduce a considerable error. The use of variable integration time step is a common approach in dynamic simulation studies but not in TSCOPF analysis. During the time intervals in which the faster transients happens a smaller integration step is used, and when the variables changes slowly, larger integration steps are applied. Thus, it is possible to reduce computation times.

However, the impact of numerical integration methods and time steps has not been fully addressed in TSCOPF studies. This paper proposes a TSCOPF model that represents the load flow equations at each bus and at each sample time. The dynamic of the system is represented using a 4th order d-q generator model that provides an accurate representation for transient stability studies. The differential equations of the model are discretized using the Theta method. Thus, it allows implementing three of the most widely used integration methods for power system simulation: forward Euler, the trapezoidal rule, and backward Euler.

The object of this study is twofold: 1) a comparative study of the impact of the use of numerical integration methods in the results given by TSCOPF; and 2) the implementation of a variable integration time step as a solution to reduce the size of the optimization problem, and consequently reduce convergence times.

LITERATURE REVIEW:

Stephen Frank, 2013: The set of optimization problems in electric power systems engineering known collectively as Optimal Power Flow (OPF) is one of the most practically important and well-researched subfields of constrained nonlinear optimization. OPF has enjoyed a rich history of research, innovation, and publication since its debut five decades ago. Nevertheless, entry into OPF research is a daunting task for the uninitiated—both due to the sheer volume of literature and because OPF's ubiquity within the electric power systems community has led authors to assume a great deal of prior knowledge that readers unfamiliar with electric power systems may not possess. This article provides an introduction to OPF from an operations research perspective; it describes a complete and concise basis of knowledge for beginning OPF research. The discussion is tailored for the operations researcher who has experience with nonlinear optimization but little knowledge of electrical engineering.

J.L.Carpentier, July 1985: Optimal power flows are basic tools for the secure and economic operation of Power Systems, but are presently applied in a few energy control centers only. The first part of this paper is dedicated to an analysis of possible statements and uses of this technique. New results providing consistency with daily power scheduling in such systems as hydro power systems are pointed out. In the second part, the main methods now available are reviewed, including parametric algorithms, with a critical analysis of the relevant performances for on-line applications. In the third part, present developments performed at Electricity de France are described. They aim at suppressing shortcomings existing in present methods. Some very new results have been obtained. These developments build up a consistent and secure operation optimization system, from daily power scheduling up to automatic control, with Optimal Power Flows as the basic tool. In particular, a new load flow technique with "implicit active reactive coupling", improvements in speed of the optimal power flow and the inclusion of the latter into a closed loop secure economic dispatch.

Satish K Joshi, January 2011: Analysis of conventional optimal power flow methods — Newton Raphson method, Fast Decoupled Load Flow method with the Optimal Power Flow Techniques based on Equivalent Current Injection. With the use of Predictor Corrector Interior Point Algorithm (PCIPA), an Equivalent Current Injection based OPF models — Equivalent Current Injection Optimal Power Flow, Decoupled Equivalent Current Injection Optimal Power Flow, and Fast Decoupled Equivalent Current Injection Optimal Power Flow. The minimization problem based on equivalent current injection has been compared with the conventional Optimal Power Flow techniques

Provas Kumar Roy, 2014: An efficient optimization procedure based on herding behavior of krill individuals, krill herd algorithm (KHA), for the solution of multi-objective optimal power flow (OPF) with the objective of fuel cost minimization, voltage deviation minimization and voltage stability improvement is proposed. This algorithm is based on the effect of the influence of a teacher on the output of learners in a class. The proposed KHA approach is carried out on the standard IEEE 30-bus, IEEE 57-bus and IEEE 118-bus systems to solve different single and multi-objective OPF problems. Simulation results of the proposed approach are compared to differential evolution (DE), modified DE (MDE), multi-objective DE (MODE), evolving ant direction DE (EADDE), particle swarm optimization (PSO), improved genetic algorithm (IGA), gradient method, biogeography-based optimization (BBO), PSO with inertia weight approach (PSOIWA), PSO with constriction factor approach (PSOCFA), real-coded GA (RGA), artificial bee colony (ABC), general passive congregation PSO (GPAC), local passive congregation PSO (LPAC), coordinated aggregation (CA), interior point method (IPM) and quantum-inspired evolutionary algorithm (QEA). The comparison demonstrates the superiority of the proposed approach and confirms its potential to solve multi-objective OPF problems.

Fadi M. Albatsh, April 2015: A new approach to selecting the locations of unified power flow controllers (UPFCs) in power system networks based on a dynamic analysis of voltage stability. Power system voltage stability indices (VSIs) including the line stability index (LQP), the voltage collapse proximity indicator (VCPI), and the line stability index (Lmn) are employed to identify the most suitable locations in the system for UPFCs. In this study, the locations of the UPFCs are identified by dynamically varying the loads across all of the load buses to represent actual power system conditions. Simulations were conducted in a power system computer-aided design (PSCAD) software using the IEEE 14-bus and 39- bus benchmark power system models. The simulation results demonstrate the effectiveness of the proposed method. When the UPFCs are placed in the locations obtained with the new approach, the voltage stability improves.

Overview of Optimal Power Flow: OPF can help in solving many problems. There are some scenarios of OPF contribution to the analysis of power systems

- In the standard description of the OPF problem, if an empty set is specified for the controls, the algorithm reduces directly to a typical power flow problem. The procedures in this case depend on the bus mismatch equations and provide the same state solution like the classic power flow, including bus voltages and branch flows.
- OPF may be associated with the constrained economic dispatch to define the optimal allocation of loads among the generators by specifying the generation cost characteristics, the network model and the load profile.
- OPF can also be used to minimize the total real power loss through reactive power dispatch. In this case, only reactive controls such as transformer tap positions, shunt capacitors and reactors, and excitation systems are used to minimize the total losses in the entire network, or in a subset of the network.
- OPF can be used to define feasible solutions or indicates if one exists using the so-called minimum of control movements strategy. According to this strategy, the objective of the optimization process is to minimize the cost function based on control deviations from the base case.
- Researchers proposed different mathematical formulations of the OPF problem that can be classified into three:
- Linear problem in which objectives and constraints are given in linear forms with continuous control variables.
- Nonlinear problem where either objectives or constraints or both combined are linear with continuous control variables.
- Mixed-integer linear and linear problems when control variables are both discrete and continuous.

OTS model:

Foundational model:

Combined with the pre-contingence transient stability constraints into OPF, the model can be described as:

1)Objective function is minimum active power loss of power system.

$$\min \quad F(x) = \sum_{i \in S_G} P_{Gi} - \sum_{i \in S_n} P_{Di}$$

Where PGi refers to the active power output of ith power source; SG is active power sources set; Sn is the set of all nodes; PDi is the active power load of ith power source.

2) Equality constraints:

There are two parts in this section, including power flow equations and swing equations of generator.

a. Power flow equations:

$$\begin{cases} P_{Gi} - P_{Di} - V_i \sum_{j=1}^{n} Y_{ij} V_j \cos(\theta_i - \theta_j - \alpha_{ij}) = 0 \\ Q_{Ri} - Q_{Di} - V_i \sum_{j=1}^{n} Y_{ij} V_j \sin(\theta_i - \theta_j - \alpha_{ij}) = 0 \end{cases} \quad i \in S_n$$

Where QRi refers to the reactive power output of ith power source; QDi is reactive power load at bus i; Vi, θi are the magnitude and phase of voltage at bus i separately; Yij, αij are magnitude and phase of transfer admittance between buses i,j.

a. Swing equations of generator.

For simplicity, a classic generator model is used in this paper. The difference equation is as follows:

$$\begin{cases} \mathrm{d}\delta_i/\mathrm{d}t = \omega_0\left(\omega_i - 1\right) \\ \mathrm{d}\omega_i/\mathrm{d}t = \left(-D_i\omega_i + P_{Gi} - P_{ei}\right)/M_i \end{cases}$$

Where δi refers to the rotor angle of ith generator; ωi is the rotor angular speed of ith generator where ω0 defines the synchronous; Di is damping value of ith generator; Mi stands for the moment of inertia of ith generator; Pei is electromagnetic power of ith generator:

$$P_{ei} = E_i \sum_{j \in S_G} E_j \left[G_{eij}\cos(\delta_i - \delta_j) + B_{eij}\sin(\delta_i - \delta_j)\right]$$

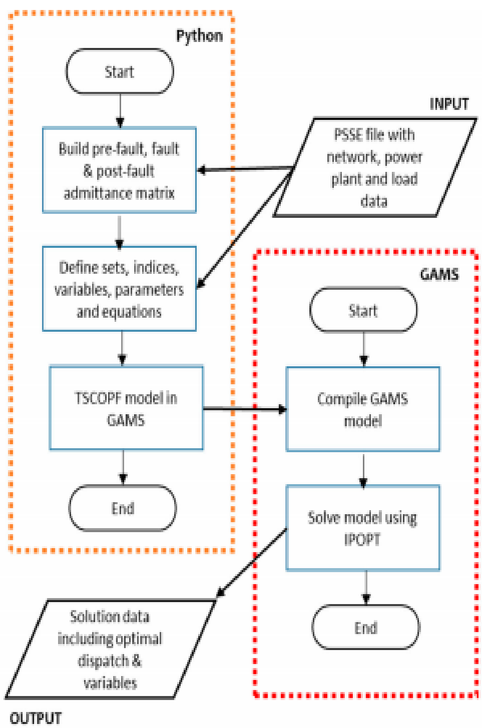
Implementation and Case Study:

The proposed problem of optimization is carried out using the software framework shown in Figure 1. First, a Python program reads data from standard PSSE files describing the network, power plants and loads. The TSCOPF model is then automatically constructed as follows: (1) It calculates the admittance matrices for the pre-fault, fault and post fault stages taking into account the information about the contingency and the switching operations; (2) It defines the set of power plants, buses, loads and parameters of the system using the data from the PSSE file. IPOPT is able to solve large scale non-linear optimization problems using a prime-dual interior point method. The proposed approach is flexible in its application to electric power systems allowing modifications of the network topology, the loads, the contingencies and the optimization solver.

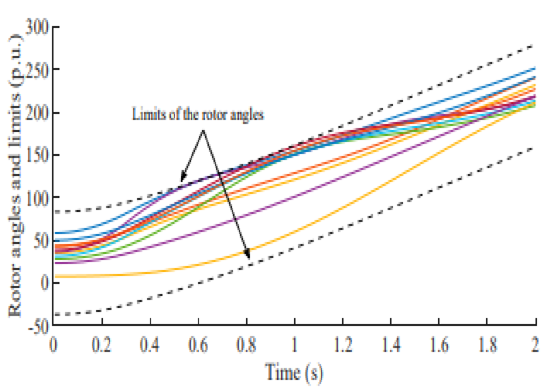
• A three-phase short-circuit occurs in the transmission line connecting buses 15 and 16—adjacent to bus 16. The fault is cleared by opening the circuit breakers at the two ends of this line after 300 ms.

• A three-phase short-circuit occurs in the transmission line connecting buses 3 and 4—adjacent to bus 3. The fault is cleared by opening the circuit breakers at the two ends of this line after 300 ms.

These faults have been selected because they pose a considerable risk to transient stability due, on the one hand, to their location in the bulk of the transmission system and, on the other hand, to the fact that the loss of the line after the clearance of the fault significantly weakens the system. In all the studied cases the rotor angle deviation at one or more synchronous generators reaches its limits, which means that the dynamic constraints affect the optimal dispatch. In other words, the solution provided by a classical OPF is not transiently stable and the TSCOPF modifies the dispatch to ensure that the solution is stable. Thus, in the studied cases the production cost of the dispatch provided by the TSCOPF is always higher than the cost of the dispatch provided by a classical OPF. As an example, Figure shows the rotor angles of all synchronous generators in one of the solved TSCOPF models; it can be seen that the upper angle constraint is reached at approximately t = 0.6 s.



Software implementation for TSCOPF



Synchronous generator rotor angles as provided by the solution of the TSCOPF when a short circuit is applied

RESULTS:

There are still many constraints and there is nonlinearity, which should be incorporated in future OPF problem. Problems related to mathematical validation, deregulated market constraints, contingencies incorporation, and renewable sources integration are latest challenges for future OPF problems. This study will assist researchers in comparing and selecting an appropriate OPF technique, to find the optimal state of any system under system constraint. This work may also be supportive for the commercial utilization of OPF. Additionally, other better techniques may also be considered for further study. The futuristic enrichment of the current study may be to develop a OPF technique, which can provide better results.

FUTURE SCOPE:

Emphasis is on the newly proposed concept of representing meshed power networks using an extended conic quadratic (ECQ) model and its amenability to solution by using interior-point codes. Modeling of both classical power control devices and modern unified power flow controller (UPFC) technology is described in relation to the ECQ network format. Applications of OPF including economic dispatching, loss minimization, constrained power flow solutions, and transfer capability computation are presented. Numerical examples that can serve as testing benchmarks for future software developments are reported on a sample test network.

CONCLUSIONS:

Optimal power flow is an optimizing tool for power system operation analysis, scheduling, and energy management. Use of the optimal power flow is becoming more important because of its capabilities to deal with various situations. This problem involves the optimization of an objective function that takes various forms while satisfying a set of operational and physical constraints. Hence, in this work authors present a comprehensive review of solution techniques and methods used for optimization of power flows. Further, techniques used for optimization of systems incorporating renewable energy sources such as microgrid, storage system, electrical vehicle, wind, and solar are also reviewed in this work. Different metaheuristic techniques used for OPF are further discussed. Different OPF problems are discussed with respect to the constraints applied and assumptions made. The traditional and metaheuristic based OPF techniques are compared with respect to different properties of OPF techniques. Different mathematical and metaheuristic algorithms used for OPF power system with conventional and renewable energy sources are discussed. A summarization of different techniques used for OPF with traditional and renewable energy sources is presented based on their adopted approach, techniques, and applications.

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