

POWER SYSTEM ANALYSIS USING MATLAB TOOLBOXES

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Abstract – This paper presents the features of several Matlab toolboxes used in power system analysis, such as MatPower Toolbox (MPT), Power System Analysis Toolbox (PSAT) and Voltage Stability Toolbox (VST). For to illustrate the capabilities of MPT for educational and research purposes, a study case based on a test system, is presented.

Keywords: power system analysis, Matlab toolboxes, optimal power flow.

1. INTRODUCTION

Power system simulation involves a wide range of timeframes, starting at microseconds when simulating fast electromagnetic transients and extending to several years in system planning studies. The same system may have to be modeled and solved in many different ways, depending upon the studies event of interest. It has been desirable to have a single software platform from which several power system analysis functions can be easily activated from the same power system [1].

In the last decade, several high-level programming languages, such as Matlab, Mathcad, Mathematica and so on, have become more popular for both research and educational purposes. Any of these languages can lead to good results in the field of power system analysis. From these languages Matlab proved to be the best user choice. The important features of Matlab are the matrix-oriented programming, plotting capabilities and a graphical environment (Simulink), which highly simplified control scheme design.

This paper presents, in the first part, the features of several Matlab toolboxes used in power system analysis, such as MatPower Toolbox (MPT), Power System Analysis Toolbox (PSAT) and Voltage Stability Toolbox (VST). The second part presents a study case based on a test system, using the MPT for to illustrate the capabilities of this tool for educational and research purposes.

2. FEATURES OF MATLAB TOOLBOXES USED IN POWER SYSTEM ANALYSIS

One of the features of the Matlab toolboxes used in the power system analysis (MatPower Toolbox (MPT), Power System Analysis Toolbox (PSAT), Voltage Stability Toolbox (VST) and so on) is the modularity

of design, facilitating future revision and expansion of softwares. This is very important for researches who are interested in developing and testing new for various power system applications.

Another feature is to provide an avenue to easily prepare input data files in commonly accepted formats for networks that are created.

The results produced by one application can be easily used either fully or partially by any other application supported by the package. For example, having this feature would facilitate initialization of transient simulations by using the corresponding power flow results [1], [2], [3].

The group of the Matlab toolboxes used in the power system analysis includes a set of application functions, which collect their inputs and provide their outputs in a form to be processed for proper presentation to user. The general configuration of the all toolboxes is presented in the Figure 1.

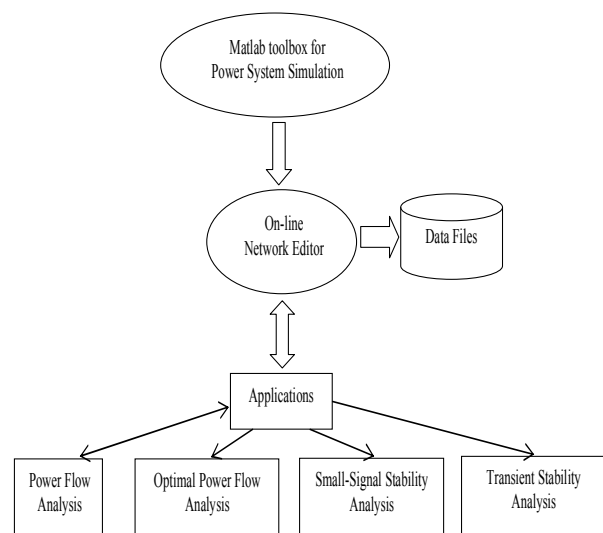


Figure1: General configuration of the Matlab toolboxes for power system analysis.

In the Matlab toolboxes for the power system analysis not all applications are presented. Thus, in the Table 1 is depicts a comparison of the Matlab toolboxes from the view point of the application functions. The applications illustrated in the table are: Power Flow (PF), Continuation Power Flow (CPF), Optimal Power

Flow (OPF), Small-Signal Stability Analysis (SSA) and Time-Domain Simulation (TDS), [2].

Toolbox	PF	CPF	OPF	SSA	TDA
MPT	*		*		
PSAT	*	*	*	*	*
VST	*	*		*	*

Table 1: Matlab toolboxes for power system analysis.

MatPower Toolbox (MPT) is a package for solving power flow and optimal power flow problems. It is intended as a simulation tool that is easy to use and modify. This Matlab package is designed to give the best performance possible while keeping the code simple to understand and modify.

Power System Analysis Toolbox (PSAT) is a Matlab toolbox for electric power system analysis and control. PSAT includes power flow, continuation power flow, optimal power flow, small signal stability analysis and time domain simulation. All operations can be assessed by means of graphical user interfaces (GUIs) and a Simulink-based library provides a user friendly tool for network design. PSAT core is the power flow routine, which also takes care of state variable initialization. Once the power flow has been solved, further static and/or dynamic analysis can be performed.

Voltage Stability Toolbox (VST) combines proven computational and analytical capabilities of bifurcation theory and symbolic implementation and graphical representation capabilities of MATLAB and its Toolboxes. It can be used to analyze voltage stability problem and provide intuitive information for power system planning, operation, and control.

Among the Matlab toolboxes presented above, it can observe that the PSAT has the most applications for power system analysis but the MPT is a simulation tool for researches and educators that is easy to use and modify.

3. OPTIMAL POWER FLOW APPLICATION

Generally, the Optimal Power Flow (OPF) is a steady state operation of the power system that minimizes the costs of meeting the load demand for a power system, while maintaining the security of the system. Another goal of an OPF is the determination of system marginal cost data. This marginal cost data can aid in the pricing of MW transactions, as well as the pricing ancillary services such as voltage support through MVar support. In solving the OPF using Newton method, the marginal cost data are determined as a by-product of the solution technique [6], [7]. Depending on the specific objectives and constraints, there are different OPF formulations. The typical objectives are:

- minimization of total generation cost;

- minimization of the active power losses;
- maximization of the degree of security of the system;
- optimization of the voltage-reactive power.

The objective function for the OPF reflects the costs associated with generating power in the system and it is assumed to be approximated by a quadratic function of generator active power output as:

$$C_i = a_i + b_i P_{G_i} + c_i P_{G_i}^2 \quad (1)$$

where: P_{G_i} [MW] - is the active output of generator “i” and a_i , b_i , and c_i - are the coefficients of the consumption characteristics.

Therefore, this objective function will minimize the total system costs.

$$F(X) = \sum_i (a_i + b_i P_{G_i} + c_i P_{G_i}^2) \quad (2)$$

The constraints from an OPF problem can be equality and inequality constraints.

The equality constraints of the OPF, generally, reflect the power balance at the buses of the system. It is common for OPF problems to be formulated in polar form, since voltage magnitude limits are treated easily as simple variable limits. Despite this merit, OPF in rectangular form has advantages in that the second derivatives of power flow equations are constants and trigonometric functions are not including.

The inequality constraints of the OPF reflect the devices limits in the power system, as well as the limits created to ensure system security. Thus generators have maximum and minimum output active and reactive powers:

$$\begin{aligned} P_{G_i \min} &\leq P_{G_i} \leq P_{G_i \max} \\ Q_{G_i \min} &\leq Q_{G_i} \leq Q_{G_i \max} \end{aligned} \quad (3)$$

Also, the transformer tap changing have a maximum and a minimum tap changing, which can be achieved,

$$tc_{ik \min} \leq tc_{ik} \leq tc_{ik \max} \quad (4)$$

For the maintenance of system security, power systems have transmission line, as well as transformer MVA ratings. These ratings may come from thermal ratings of conductors, or they may be set to a level due to system stability concerns:

$$|S_{ik}|^2 - |S_{ik \max}|^2 \leq 0 \quad (5)$$

To maintain the quality of electrical service and system security, buses voltages, usually, have a desired voltage profile,

$$U_{i \min} \leq U_i \leq U_{i \max} \quad (6)$$

In order to handle the variables in the OPF problem efficiently, it is convenient to separate them into three categories: controls, states, and constraints:

- **Control variables** correspond to quantities that can be arbitrarily manipulated, within their limits, in order to minimize the costs. These include generator MW outputs (P_{G_i}) transformer tap changing (tc_{ik}).
- **States variables** correspond to quantities that are set as a result of the controls, but must be monitored. They are also of interest at the solution. The states include all system voltages and angles (U_i, θ_i).
- **Constraint variables** are variables associated with the constraints. These include all the Lagrange multipliers.

4. CASE STUDY

This section illustrates the OPF application from the MPT for a 14-bus test system, Figure 2.

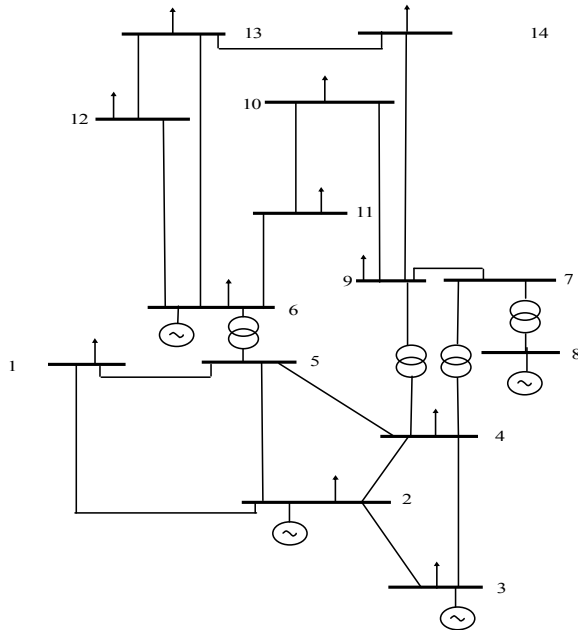


Figure 2: 14-bus Test System.

MPT has a generalized OPF formulation that allows general linear constraints on the optimization variables. The optimization algorithm uses a sequential quadratic programming (SQP) method. In this method, the function solves a quadratic programming (QP) subproblem at each iteration.

Thus, OPF solver in MPT is based on a non-linear constrained optimization function in Matlab's Optimization Toolbox. MPT provides this function with two m-files which it uses during for the optimization. One computes the objective function, F ,

and the constraint violations, at a given point, X , and the other computes their gradients.

The m-files are used to solve systems with polynomial cost function. Thus, the cost functions are included in a straightforward way into the objective function. Clearly, this method works only for convex cost functions.

In the Table 2 the bus data are indicated. The bus type can be:

- PQ bus – 1;
- PU bus – 2;
- slack bus – 3.

Bus	Type	P_d [MW]	Q_d [MVar]
1	3	0	0
2	2	21.7	12.7
3	2	94.2	19
4	1	47.8	-3.9
5	1	7.6	1.6
6	2	11.2	7.5
7	1	0	0
8	2	0	0
9	1	29.5	16.6
10	1	9	5.8
11	1	3.5	1.8
12	1	6.1	1.6
13	1	13.5	5.8
14	1	14.9	5

Table 2: Bus Data for Test System

In Figure 3 the final results of OPF application for the 14-bus test system, using MPT, are presented.

How many?	How much?	P (MW)	Q (MVar)
Buses	14	Total Gen Capacity	772.4
Generators	5	On-line Capacity	772.4
Committed Gens	5	Generation (actual)	268.3
Loads	11	Load	259.0
Fixed	11	Fixed	259.0
Dispatchable	0	Dispatchable	0.0 of 0.0
Shunts	1	Shunt (inj)	0.0
Branches	20	Losses ($I^2 \cdot R$)	9.29
Transformers	3	Branch Charging (inj)	-
Inter-ties	0	Total Inter-tie Flow	0.0
Areas	1		

	Minimum	Maximum
Voltage Magnitude	1.014 p.u. @ bus 4	1.060 p.u. @ bus 1
Voltage Angle	-14.27 deg @ bus 14	0.00 deg @ bus 1
P Losses ($I^2 \cdot R$)	-	2.90 MW @ line 1-2
Q Losses ($I^2 \cdot X$)	-	8.86 MVar @ line 1-2

Figure 3: The results of OPF application using MPT.

5. CONCLUSIONS

The paper presents several Matlab toolboxes can be used in power system analysis. These toolboxes come with a variety of procedures for static and dynamic analysis that can be used with easiness in educational and research activities.

One of the features of these Matlab toolboxes is the modularity of design, facilitating future revision and expansion of softwares. This is very important for researches who are interested in developing and testing new for various power system applications.

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