Chapter 54
The Simulation of Static and Transient Stability Enhancement of Power System by Installing UPFC

Zhensheng Wu, Ronghuan Guo and Lu Yin

Abstract Unified power flow controller (UPFC) is a device which controls active power and reactive power in order to enhance the static and stability of power system. In power system analysis software (PSD-BPA), the model of UPFC is not perfect and the simulation model of local grid in MATLAB/Simulink can be built precisely. Thus, this paper introduces a simulation method of combining MATLAB/Simulink and PSD-BPA to simulate the power flow of local grid. First, extracting the parameters of the local power grid with UPFC accurately was important. Second, the extracting parameters were imported to MATLAB/Simulink to build the simulation model of local power system and then the process of simulation was carried out. Last, the contrastive analysis of MATLAB/Simulink simulation results and the power flow simulation of PSD-BPA verifies the correctness of this model. Then, the model of power system with UPFC worked well during the abnormal operating conditions of power network, while an actual example was introduced.

Keywords MATLAB/Simulink · PSD-BPA · Power flow · Unified power flow controller (UPFC)

54.1 Introduction

Power flow calculation is one of the most basic operations of power system. Due to the uneven flow distribution or unreasonable delivery process often cause overloading of individual transmission lines, sending in adverse direction and repeating power shocks and other problems, which seriously affects power quality and power

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transmission efficiency [1]. It requires to control flexibly power flow of system and maximizes the use of existing power transmission network structure to improve efficiency and to provide users with a more stable and more economical electricity environment.

For a long time, people have done a lot of research on power system optimal control of power flow and fill effectively the technology gap of power system, and one of the most widely affected areas is the development of power electronics technology. Flexible AC transmission system (FACTS) technology used to promote the rapid development of power system control technology is the sign of progress, and UPFC is one of the devices that are most representative, comprehensive, and powerful, which could control transmission line current and node voltage vector at any time throughout active power and reactive power [2, 3]. Key technologies of unified power flow controller (UPFC) will help solve the transmission bottleneck problems caused by the uneven flow of distribution grid. It effectively improves power transmission capacity and power grid asset utilization efficiency. And UPFC reactive power provides the necessary support to improve the voltage level of the grid control.

PSD-BPA trends and transient stability program (formerly the Chinese Version BPA program) as "PSD System Software Tools," an important part in the actual application process has been continuously improved and increased to guide the national network and the regional power grid planning, design, research and production work. According to the related research projects of China Electric Power Research Institute in recent years, the national network operation, planning, testing, and debugging, a lot of improvements and developments of new features of PSD-BPA trends and transient stability program have been accomplished. Among power system analysis software, PSD-BPA is convenient for power flow calculation, but the simulation model of UPFC is not perfect and does not achieve active power and reactive power decoupling control [4, 5]. Simulink can accurately simulate the UPFC, but it is very complex to build the whole power network model.

In this paper, a joint simulation method of two kinds of simulation tools with PSD-BPA and MATLAB/Simulink is introduced. First, select the required application of the local power grid model which uses UPFC device. Besides the selected local grid, power network model is equivalent to form an infinite power source of internal resistance. Extract the parameters of the power supply, the load parameters, equivalent circuit parameters, and trend data from the PSD-BPA. Then, it was imported to MATLAB power system simulation model. Without UPFC, under normal operating conditions or N-1 line of the operating conditions, each node voltage and transmission line power flow determines the correctness of MATLAB Model. The UPFC device was further added to MATLAB power system simulation model and the model simulated according to the desired control effect. Finally, an actual example was introduced in the Beijing area.

54.2 UPFC Working Principle and Mathematical Model

UPFC is a series–parallel hybrid apparatus, which can control, respectively, active power, reactive power, and voltage, for the optimal operation of the system, thus improving the transient stability of the system, and it plays a significant role in oscillation damping system [6]. Schematic diagram of UPSC is shown in Fig. 54.1, which consists of two common DC capacitor voltage source converter. Converter I is in parallel connection to system by transformer, and not only can it provide active power for converter II, but also it can absorb or inject reactive power of power system. It can be seen as a parallel controllable static VAR compensator (STATCOM). Converter II is in series connection to system by transformer and injects a series voltage amplitude and phase adjustable to control line power, which can be seen as controllable static synchronous series compensator (SSSC) [7–9].

The mathematical model of UPFC is mainly based on steady-state mathematical model, and topological structure and output model are mainly adopted [10]. The former method is clear to analyze the internal structure of UPFC, and mathematical model is more complex [11, 12]. From the perspective of the external characteristics of the output model is simple, and the equivalent circuit of UPFC established by this method is shown in Fig. 54.2. This paper mainly uses the output model

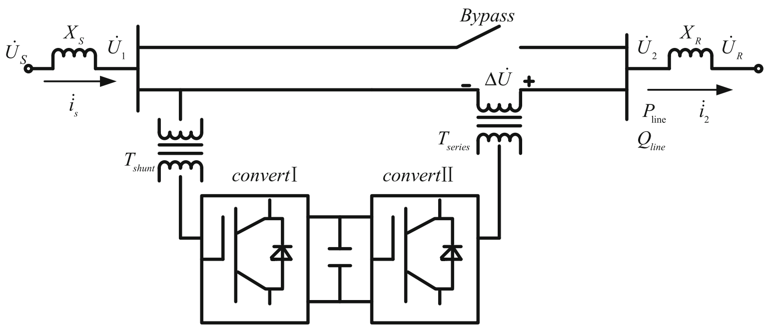

Fig. 54.1 UPFC schematic diagram

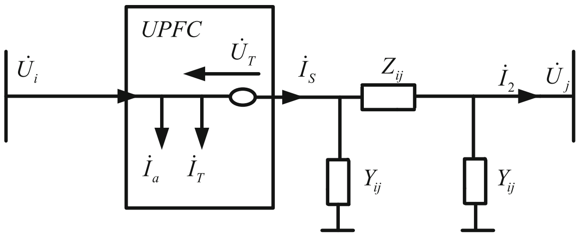

Fig. 54.2 UPFC equivalent circuit

method. UPFC is equivalent to a parallel current source and voltage source in series, parallel part to compensate the system reactive power function, which plays a significant role in controlling the power flow in the transmission.

54.3 Extract Local Parameter from PSD-BPA and Process

54.3.1 Analysis of Parameters Needed by MATLAB Simulation Model

In the ideal case, we looked from the local grid nodes toward the side of the whole grid and the grid side can be equivalent to infinite power and internal resistance. The power supply parameters include power supply voltage and internal impedance. The power system model in MATLAB/Simulink needs the amplitude and phase of the voltage and the internal impedance. With regard to the nodes which indirectly contact with the power supply side of the large power network, it can be considered as the load node and the load consumption power of the node was needed. The equivalent network parameter was power system model of transmission line impedance. In the PSD-BPA, there were some transmission lines indirectly connected between the nodes and the transmission line can be processed equivalent in MATLAB/Simulink. The power internal impedance, the impedance of the equivalent circuit, the node voltage, and the distribution of the power system flow between the nodes were extracted directly from the PSD-BPA. The amplitude and phase of power supply were accessed by the output power and node voltage calculation.

54.3.2 Extract the Parameters from the Local Power Grid

First, data files were selected from PSD-SCCPC and needed to be calculated, which was to read the network topology data. We chose “network equivalence” option, opted for several nodes of the local power grid which put UPFC into use and did equivalent calculation. The results were saved in the form of * .list, and the output calculation result was power system established model in MATLAB/Simulink. Secondly, in the PSD-BPA geographic wiring diagram, we found the relevant nodes in the local power network with UPFC device and the power flow of corresponding line among the nodes and the voltage amplitude and phase of the nodes were read.

54.3.3 Calculate the Parameters from the Local Power Grid

In the PSD-BPA geographic wiring diagram, amplitude and phase of node voltage parameters and power flow are the actual value, which can be applied directly. The unit of source impedance and line impedance obtained from PSD-SCCPC was pu; however, the parameters for MATLAB/Simulink mod were actual values, so obtained data from PSD-BPA were needed to process. In the BPA, the voltage sources are represented by a generator having internal impedance. The impedance of load is in per unit on the system-specified base. So, to find the impedance in ohm, the per-unit value is multiplied by the base impedance of the circuit,

$$Z = Z_{\cdot} \frac{U_B^2}{S_B} \tag{54.1}$$

$$L = \frac{X}{2\pi f} \tag{54.2}$$

The formula (54.2) represents the relationship between reactance and inductance. At a known node voltage, you can get a power supply voltage with the following formula,

$$\dot{U}_S = \dot{U}_m + Z_S \times \left(\frac{S_m}{\dot{U}_m}\right)^* \tag{54.3}$$

$$S_j = S_k + \left(\dot{U}_j - \dot{U}_k\right) \times \left(\frac{\dot{U}_j - \dot{U}_k}{Z_{jk}}\right)^{\cdot} \tag{54.4}$$

Where, represents the first node to the end of the line power output. It means the line impedance transmission from the first to the end.

54.4 MATLAB/Simulink Modeling and Simulation

54.4.1 Establish Power System Model

Simulink is a software package of MATLAB that provides the dynamic system model, simulation, and analysis. Here are the establishments of the local power grid model in MATLAB/Simulink-specific process. Run Simulink, open the power system module library SimPowerSystems Simulink to establish the experimental model, select three-phase source module as power supply, and set the neutral point grounding. Three-Phase VI Measurement is selected as bus because of having the voltage measurement module, and its initial parameter settings are the voltages of phase to ground. Three-phase series RLC load is used as load module, whose initial voltage is the node voltage of PSD-BPA, and the consumption of load power is calculated according to Kirchhoff's current law. Transmission line model selection is three-phase PI section line, and its initial parameters depending on the line network parameters are derived from PSD-BPA. Simulink has a packed UPFC module which can be used according to the need. The amplitude and phase of the power supply module and the impedance of the transmission line can be filled out directly after the definition of the program initialization. The voltage amplitude and phase of each node are displayed by Scope and display models. Powergui (Power Graphical User Interface) module is for simulation of power system, which provides graphical user interface analysis. As we only focus on steady-state power flow control effect, the choice is phasor simulation pattern. The following example is double transmission lines with UPFC between A Power Plant and D Power Plant to illustrate the modeling process. In normal operating condition, the power flow of A to B is four times that of A to D, and thus, the distribution of power flow is severely uneven. At the same time, when the double transmission of A Power Plant to B Power Plant occurred N-1 abnormal operating condition, power flow of single transmission line would reach 478.4 MVA and transmission line would be overloaded. The main advantage is that UPFC device can control the transmission line flow to relieve overloaded transmission line pressure, improve light-load power line transmission, mine delivery potential of power flow section, and optimize network operation mode. Therefore, in order to solve the overload problem of A Power Plant to B Power Plant under double-circuit transmission line at N-1 abnormal operating condition, UPFC device was installed between A Power Plant and B Power Plant to improve the current power distribution on the sectional line. The structure of local power network is shown in Fig. 54.3. In Fig. 54.3, the three nodes of A, D and E connected with large grid, and the large grid that connected with these three nodes were equivalent to internal

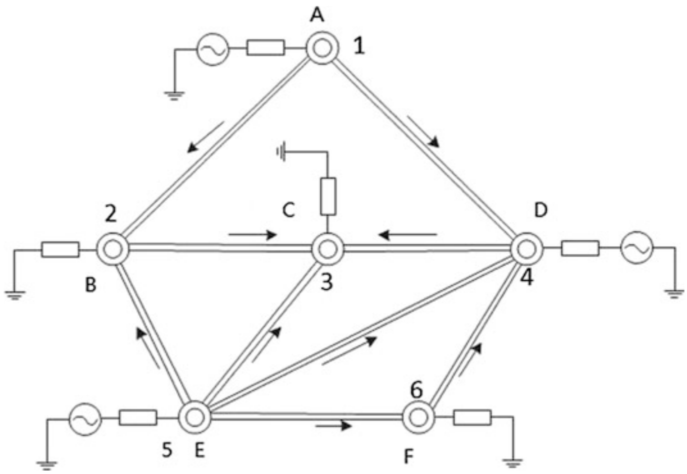

Fig. 54.3 The schematic diagram of local power grid

impedance of the infinite power supply. And three nodes B, C, and F connected to the power grid were load nodes, so that it would be directly equivalent to load. In addition, there was no existence of the line of E node to C node, but in fact there are connections with other nodes and it will be equivalent to double-circuit line of E node to C node. The same principle applies to E node to D node.

54.4.2 MATLAB/Simulink contrast with PSD-BPA in the Modeling and Simulation

The extraction of node voltage, power supply internal impedance from PSD-BPA are shown in Table 54.1. And the extraction of line impedance and power flow are shown in Table 54.2.

Using formula (54.1) and (54.2), the power inside the power source within Table 54.1 can be transformed into the actual value of line impedance in Table 54.2.

Table 54.1 Node voltage and the independence of source extracted by PSD-BPA

Node	Voltage (kV∠°)	Node property	Positive-sequence admittance (pu)	Negative-sequence admittance (pu)	Zero-sequence admittance (pu)
A	227.2∠−50.5	Power supply	0.0155 − j2.9449	0.0155 − j2.9449	0.0154 − j2.2654
B	226.1∠−51.0	Load	–	–	0.0000 − j0.7616
C	225.3∠−51.4	Load	–	–	0.0298 − j2.4124
D	226.1∠−50.7	Power supply	0.1335 − j3.4378	0.1335 − j3.4382	0.8552 − j7.9515
E	226.3∠−50.1	Power supply	0.3082 − j11.6731	0.3084 − j11.6754	0.4419 − j10.410
F	226.2∠−50.2	Load	–	–	0.0000 − j0.8554

Table 54.2 The parameters of transmission line extracted by PSD-BPA

Transmission line	Power flow (MW + jMvar)	Positive-sequence resistance (pu)	Negative-sequence resistance (pu)	Zero-sequence resistance (pu)
A–B	533.2 + j204.6	0.0025 + j0.0171	0.0025 + j0.0171	0.0183 + j0.0490
A–D	120.2 + j100.6	0.0075 + j0.0353	0.0075 + j0.0353	0.0243 + j0.1107
B–C	535.2 + j143.4	0.0025 + j0.0124	0.0025 + j0.0124	0.0167 + j0.0325
D–C	290.2 + j51.6	0.0044 + j0.0400	0.0044 + j0.0400	0.0335 + j0.1199
E–B	203.4 − j6.8	0.0080 + j0.0771	0.0080 + j0.0771	0.0614 + j0.2329
E–F	218.4 + j6.2	0.0012 + j0.0077	0.0012 + j0.0077	0.0088 + j0.0217
F–D	–	0.0096 + j0.0819	0.0096 + j0.0819	0.0727 + j0.2435
E–C	–	0.0258 + j0.2773	0.0258 + j0.2773	0.1297 + j1.0807
E–D	108.2 − j13.4	0.0216 + j0.1742	0.0216 + j0.1742	0.2700 + j0.6848

At the same time, according to Table 54.1, it gives the node voltage amplitude and phase, and by formula (54.3) and (54.4), we can obtain the amplitude and phase of the power supply voltage and further calculate the load node power consumption. Then, these results were imported to MATLAB/Simulink. The simulations run in two cases: One is the model in normal operating condition and the other is the double-circuit line n – 1 operation mode of A node to B node of model. The results of the simulation were compared with the corresponding PSD-BPA simulation result, as shown in Tables 54.3, 54.4, 54.5 and 54.6.

Table 54.3 The comparison between PSD-BPA and MATLAB/Simulink power flow simulation under normal condition

Transmission line	Power flow simulation of PSD-BPA (MW + jMvar)	Power flow simulation of Simulink (MW + jMvar)
A–B	533.2 + j204.6	534.2 + j203.7
A–D	120.2 + j100.6	119.8 + j101.4
B–C	535.2 + j143.4	534.9 + j141.2
D–C	290.2 + j51.6	291 + j54.1
E–B	203.4 − j6.8	202.1 − j7.7
E–F	218.4 + j6.2	216.9 + j10.6
F–D	108.2 − j13.4	106.7 − j9.0

Table 54.4 The comparison between PSD-BPA and MATLAB/Simulink node voltage simulation under normal condition

Node	Voltage simulation of PSD-BPA(kV∠°)	Voltage simulation of Simulink (kV∠°)
A	227.2∠−50.5	227.2∠−50.5
B	226.1∠−51.0	226.1∠−51.0
C	225.3∠−51.4	225.4∠−51.4
D	226.1∠−50.7	226.2∠−50.7
E	226.3∠−50.1	226.3∠−50.1
F	226.2∠−50.2	226.2∠−50.2

Table 54.5 The comparison between PSD-BPA and MATLAB/Simulink power flow simulation under the transmission line $N - 1$ condition

Transmission line	Power flow simulation of PSD-BPA (MW + jMvar)	Power flow simulation of Simulink (MW + jMvar)
A–B	446.4 + j172.1	442.6 + j171.4
A–D	207.2 + j130.2	202.2 + j131.6
B–C	471.2 + j119.6	468.7 + j117.3
D–C	350.6 + j74.8	350.9 + j76.8
E–B	226.6 + j5.0	227.3 + j3.6
E–F	203.2 + j1.8	203.0 + j5.9
F–D	93.0 − j17.8	93.0 − j13.6

Table 54.6 The comparison between PSD-BPA and MATLAB/Simulink node voltage simulation under the transmission line $N-1$ condition

Node	Voltage simulation of PSD-BPA (kV∠°)	Voltage simulation of Simulink (kV∠°)
A	227.5∠−50.3	227.6∠−50.3
B	225.7∠−51.2	225.7∠−51.2
C	225.0∠−51.5	225.1∠−51.5
D	226.1∠−50.7	226.1∠−50.7
E	226.1∠−50.2	226.2∠−50.1
F	226.1∠−50.2	226.1∠−50.2

54.4.3 UPFC Simulation

From Table 54.3, and Table 54.4, it is evident that the system was in motion in the normal condition, and active power flow of A node to B is more than four times that of A node to D node, severely unbalanced distribution trend. At the same time, as is shown in Table 54.5, when the double-circuit line $N-1$ fault of A node to B node occurred, power flow of a single line reached 478.4 MVA (line allows the transmission capacity of 476 MVA). As a consequence of this, the circuit overloaded. In order to solve the problem of the—double-circuit lines of A node to B node under the abnormal conditions of $n-1$, installed UPFC device between A node and B node to improve the distribution of section flow. In order to avoid the situation of transmission line overload and keep consistent system distribution of power flow normal, we set active power 400 MW and reactive power 200 Mvar as the goal of double-circuit line of A to B under n − 1 fault condition. In fact, the result of local power grid model in MATLAB/Simulink which was added to UPFC was that active and reactive power flow, respectively, reached the desired control objectives of 400.5 MW and 199.9 Mvar. Meanwhile, based on the voltage drop and current, one can obtain the required series side capacity of UPFC 2.24 MVA. The parallel side capacity of UPFC is needed according to the reactive capacity of the network.

54.5 Conclusion

In order to meet the simulation requirement of UPFC in power system, a joint simulation method of two simulation software, MATLAB/Simulink and PSD-BPA were presented in this paper. MATLAB/Simulink built application of UPFC device in the local network model. Outside the grid model of power grid was equivalent to infinite power and the form of resistance or load, thereby reduced the complexity of the simulation. Extract every transmission line in the local power grid impedance, power flow calculation, node voltage, power grid of the power supply voltage, impedance and load power consumption from PSD-BPA. Then import them to

MATLAB/Simulink to build the system model. In addition, the UPFC device model is added to MATLAB/Simulink, and the simulation is carried out according to the target. At the end, this paper presents double-circuit line with UPFC device in Beijing Power Plant as an example for researching and practical application.

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