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Enhancing Power System Reliability Using Unified Power Flow Controller

KEYWORDS: Composite system reliability, optimal control mode and settings, unified power flow controller (UPFC)

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ABSTRACT *Unified power flow controller is one of the facts devices used for real and reactive power control. The use of upfc can improve the power system reliability. In this paper we are discussing about various control modes and settings of upfc. A two source power injection model is used for representing upfc and a mixed integer linear optimization problem is used for solving problems affecting reliability. In this method for finding the remedial action cost, first we are analyzing contingency screening method.*

INTRODUCTION

The unified power flow controller (upfc) is one of the most widely used flexible ac transmission systems devices that have used for the control and optimization of power flows. This paper is aimed at finding settings to improve the reliability of power systems and the optimal UPFC control mode. A selected set of contingencies are analyzed and the optimal power flow (OPF) is used to minimize RAC and calculate the optimal UPFC injections and the sensitivity of RAC to UPFC injections. The results of contingency analyses are used to calculate post-contingency injections of UPFC and to estimate the ESRAC. The optimal UPFC control mode [2]and settings are obtained by solving the proposed mixed-integer nonlinear optimization problem. The impact of UPFC control modes and settings on reliability indices are discussed. Then proposed method is applied to a test system to find the optimal control mode and setting of UPFC and to discuss various aspects of the method performance.

UPFC: STRUCTURE, OERATION, AND CONTROL

A UPFC consists of two identical inverters which are connected in parallel and series to power systems through corresponding power transformers. Fig. 1 shows the single line diagram of a UPFC installed in a power system in which the UPFC is represented by a voltage source models

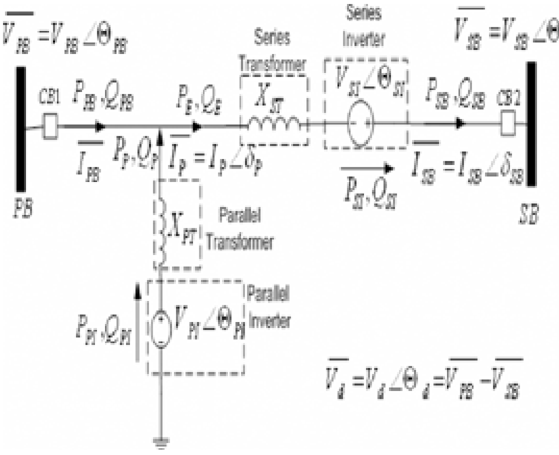

Fig.1 Single line diagram of UPFC.

In Fig. 1, the UPFC is installed between buses PB and SB. The net active power exchange of inverters is zero if we neglect power losses in inverters. Each inverter is equipped with a control unit for firing commands according to measured signals and control modes of the inverter. The designated power system parameters are regulated at the associated settings.

$$P_{SI} + P_{PI} = 0 \qquad (1)$$

Control modes are given as follows.

Series inverter

Power Flow control Mode (PFM): Fig. 1 shows that UPFC regulates P_{SB} and Q_{SB} independently at associated settings. This control mode distinguishes UPFC from STATCOM and SSSC.

Voltage Control Mode (VCM): V_{SI} and θ_{SI} are determined for regulating at associated settings.

Voltage Injection Mode (VIM): V_{SI} and θ_{SI} are determined to maintain at associated settings.
Parallel inverter

Reactive Control Mode (RCM): a constant positive or negative reactive power Q_{PB} is injected at PB.

Voltage Control Mode (VCM): Q_{PI} is automatically regulated in Fig. 1 to maintain V_{PB} at associated settings.
In this paper, the two-source power injection model is used to represent the UPFC in optimal power flow studies. In this model, parallel source (PS) and series source (SS) are connected to PB and SB, respectively, so that the total real power injection of PS and SS is zero.

$$P_{PS} = P_{SS} \qquad (2)$$

In Fig. 2, once the three independent injections of PS and SS are known, the voltage and current of series and parallel inverters in Fig. 1 are calculated as follows

$$\overline{I_{SB}} = \frac{P_{SS} - jQ_{SS}}{V_{SB}*} = \qquad (3)$$

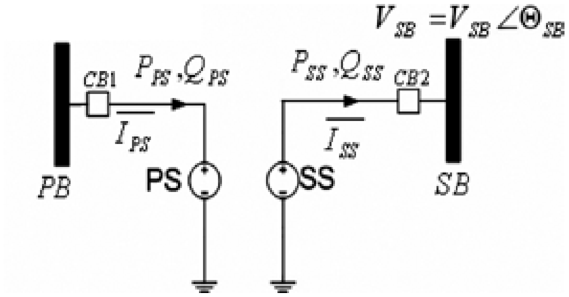

Fig.2. Two-source power injection model for UPFC.

$$\overline{I_{PB}} = \frac{P_{SS} - jQ_{PS}}{V_{PB^*}} \qquad (4)$$

$$V_{SI} < \theta_{SI} = \overline{V_{SB} - V_{PB}} - jX_{ST}\overline{I_{SB}} \qquad (5)$$

$$V_{PI} < \theta_{SI} = \overline{V_{PB}} + jX_{PT}\,(\overline{I_{SB}} - \overline{I_{PB}}) \qquad (6)$$

Control modes associated with series and parallel inverters are also considered for PS and SS, respectively, as

$$\text{ms} = \begin{cases} 1.PFM \\ 2.VCM \\ 3.VIM \end{cases} \qquad (7)$$

$$\text{mp} = \begin{cases} 1.RCM \\ 2.VCM \end{cases} \qquad (8)$$

UPFC has other operating states for operating as STATCOM or SSSC when exploiting only one of parallel or series inverters, respectively. In these states, the device manipulates power flows for the operation and control of power systems [1]. The impacts of these two operating states on the system reliability are much smaller than the case when the UPFC operates in the up state. In this paper, the two-state up/down model is used for reliability studies. The proposed method finds the optimal control mode and settings when the UPFC is in the up state. The method can further be extended to include other operating states of UPFCs. The composite system reliability analysis considers various power system contingencies and performs post-contingency remedial actions [7]. The system reliability indices including expected unserved energy cost (EUEC) and expected load curtailment (ELC), are given as

$$\text{EUEC} = \sum_{j=1}^{NC} P_j\, CLC_j \qquad (9)$$

$$\text{ELC} = \sum_{j=1}^{NC} \sum_{i=1}^{NLD} F_j\, CL_{j,i} \qquad (10)$$

$$\text{CLC}_j = \sum_{i=1}^{NL} CL_{j,i} * D_j * CC_i(D_j) \qquad (11)$$

For each contingency, CLC_j and $CL_{j,i}$ are obtained by minimizing RAC as

Min $RAC_j = CLC_j + GRC_j$ j = 1,2,   (12)

GRC =   (13)

Optimization is subjected to

P_{ming} P_g 1.1 * P_{maxg} g = 1..NG (14)

Q_{ming} Q_g 1.1 * Q_{maxg} g = 1..NG (15)

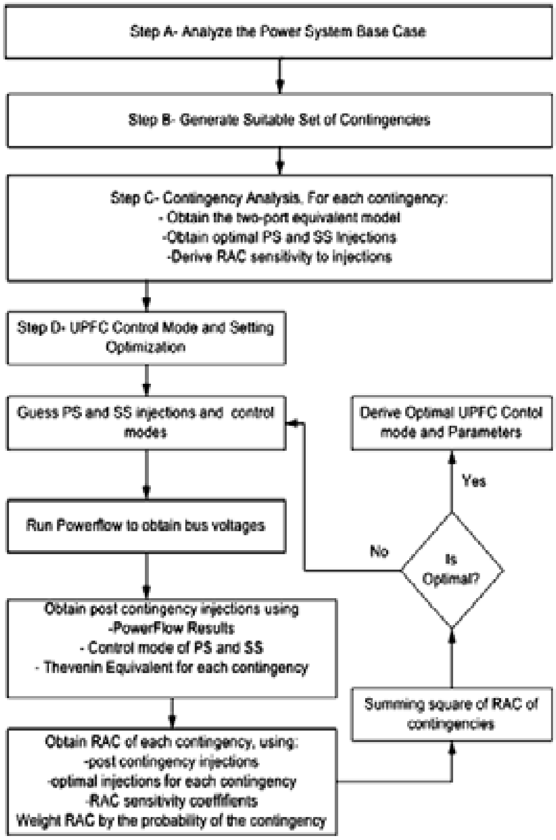

Fig. 3. Flowchart of the proposed method

0.9 V_b 1.08 p.u b = 1..NG   (16)

L_l 1.1 L_l^N l = 1..NL   (17)

$f_j(V,,P,Q) = 0$ (18)

in which (18) represents power flow for contingency .

DESCRIPTION OF METHOD

Step 1) selection of base case;
Step 2) contingency selection;
Step 3) contingency analysis;
Step4) optimization of UPFC control modes and settings. Fig. 3 describes the procedure for calculating the optimal UPFC control mode and settings.

DESCRIPTION OF METHOD

Selection of Base Case

The power system base case, without UPFC, minimizes the total dispatch cost of committed generating units by applying the optimal power flow as

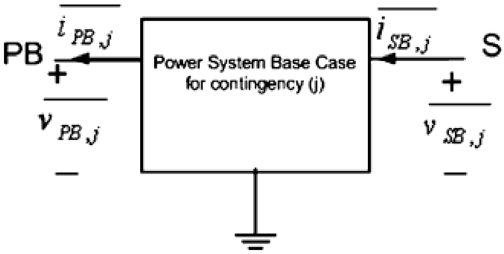

Fig 4. Two-port model of the power system base case for contingency (j)

$$\text{st}\begin{cases} fj(V,\delta,P,Q) = 0 \\ \text{Pming} \le \text{Pg} \le 1.1 * \text{Pmaxg} \\ \text{Qming} \le \text{Qg} \le 1.1 * \text{Qmaxg} \\ 0.9 \le \text{Vb} \le 1.08 \\ L_l \le 1.1 \le L_l^N \end{cases} \qquad (20)$$

Using the base case solution, the UPFC is installed at designated PB and SB buses

Contingency Selection

Reliability assessment includes the analyses of selected contingencies. The post contingency condition of certain contingencies, including those which disconnect PB or SB, will not be affected by UPFC injections. These contingencies are excluded from the optimal calculation of UPFC control mode and settings. A NC set of contingencies is selected accordingly.

$$\begin{bmatrix} \overline{v_{PB,j}} \\ \overline{v_{SB,j}} \end{bmatrix} = \begin{bmatrix} \overline{v^{+}_{PB,j}} \\ \overline{v^{+}_{PB,j}} \end{bmatrix} - \begin{bmatrix} Z_{PB,PB,j} & -Z_{PB,SB,j} \\ Z_{PB,SB,j} & Z_{SB,SB,j} \end{bmatrix} \begin{bmatrix} \overline{i_{PB,j}} \\ \overline{i_{SB,j}} \end{bmatrix} \qquad (20)$$

In Fig. 1, UPFC is disconnected by opening the breakers CB1 and CB odel parameters $Z_{PB,PB,j}$, $Z_{SB,SB,j}$ and $Z_{PB,SB,j}$. sis is performed for contingency (j), and $\overline{v^{+}_{PB,j}}, \overline{v^{+}_{SB,j}}$ are obtained. Then CB1 and CB2 are closed and the contingency is analyzed to minimize RAC in which active and reactive dispatch of generating units, PS and SS injections, and load curtailments are considered as remedial actions. For NC contingencies, the equations of (11)–(17) and (22) are solved to incorporate PS and SS injections

$$Fj(V,\partial,Q,Q_{PS},P_{SS},Q_{SS}) = 0 \qquad (22)$$

in which (22) represents the power flow equations for contingency (j) when incorporating UPFC. Here, (2)–(6) associated with the UPFC as well as limits on voltage, current, and apparent power of the inverters are represented as

$$V_I^{Min} \le V_{SI} \le V_I^{Max} \qquad (23)$$

$$I_{SB} \le I_I^{Max} \qquad (24)$$

$$V_I^{Min} \le V_{PI} \le V_I^{Max} \qquad (25)$$

$$I_P \le I_I^{Max} \qquad (26)$$

We obtain the following items by solving (11)–(17), (22) and considering (23)–(26) for each contingency j :

- optimal UPFC injections for PS and SS

- sensitivity coefficients of RAC. for the contingency j to injections of PS and SS, i.e.,

$$SE_{QPS,j} = \left.\frac{\partial RAC_j}{\partial Q_{PS}}\right|_{Q^{+}_{PS,j}} \qquad (27)$$

$$SE_{PSS,j} = \left.\frac{\partial RAC_j}{\partial P_{SS}}\right|_{P^{+}_{SS,j}} + \left.\frac{\partial RAC_j}{\partial P_{PS}}\right|_{P^{+}_{PS,j}} \qquad (28)$$

$$SE_{QSS,j} = \left.\frac{\partial RAC_j}{\partial Q_{SS}}\right|_{Q^{+}_{SS,j}} \qquad (29)$$

These items as well as the parameters of two-port equivalent model are used in the next step to find the optimal control mode and settings.

Optimization of Control Mode and Settings

This part uses the parameters and coefficients obtained in step C to calculate the optimal UPFC control mode and settings. The binary variables IP_{MP} and IS_{MS} represent the selection of control modes for PS and SS

Once the optimal PS and SS injections are found, UPFC settings are determined by applying (3)–(6).

NUMERICALRESULT

In order to demonstrate the impact of UPFC control modes and settings on reliability, the WSCC nine-bus test system [8] is used in Fig. 5. The system is modified by adding a 230 kV transmission line from B4 to B8. Since the WSCC reliability data are unavailable, those of the IEEE reliability test system (IEEE-RTS) [9] are used.

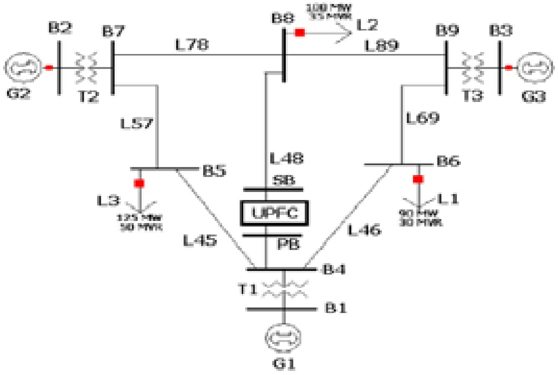

Fig.5 UPFC application

TABLE 1
UPFC specifications

UPFC Component	Specification
Inverter	100 MVA, 10 KV
Series Transformer	100 MVA, 10/30 KV
Parallel Transformer	100 MVA, 10/230 KV

TABLE 2
Reliability indices with and without UPFC

No	Control mode of parallel inverter	Control mode of series inverter	EUEC (K$)	ELC (MW)
1	-	-	1518	230
2	RCM	VIM	1321.98	200.3
3	VCM	VIM	1380.06	209.1
4	RCM	VCM	1426.9	219
5	VCM	VCM	1472.14	222.2
6	RCM	PFM	1749	265
7	VCM	PFM	1768.9	268

TABLE 3
UPFC control mode and settings

Inverter	Mode	Settings	PS/SS injections
series	VIM	0.02-61	3+j14.2 MVA
parallel	RCM	-21.3 MVAR	-3+j21.2 MVA

. So proper selections of the UPFC control modes and settings can lead to a considerable enhancement of system reliability. The best reliability enhancement is achieved when the parallel inverter operates in the RCM mode and the series inverter operates in the VIM mode.

CONCLUSION

This paper presented the optimal control mode and settings of UPFCs. A two-source power injection model was used for UPFC and the impact of UPFC control modes and settings on reliability indices were investigated. It was shown that the UPFC control mode has a considerable impact on post-contingency conditions and reliability indices. The approach estimated the RAC associated with UPFC power injections and estimated costs were then used in a mixed-integer nonlinear optimization problem to find the optimal UPFC control mode and settings. The proposed method was extended to find the optimal control mode and settings of two UPFCs. The application of the second UPFC did not have a considerable impact on the reliability indices of the given power system.

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