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Improve Static Voltage Stability Edge with Optimal Placement of UPFC and PST

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ABSTRACT: The main goal of this paper is finding optimal place of unified power flow controller (UPFC) and phase shifter (PST) in the power systems. In other words, the main concentration is on connecting FACTS and OPF tools opinion using PST and UPFC power injection model to find the best place of setting these elements in power networks. The objective function of maximizing static voltage stability edge (system loadability factor) is discussed in this paper. Simulation results are offered on IEEE 118_ bus standard network and they suggest that proposed algorithm includes the better resolution and there is a more little time than the other placement methods.

Key words: OPF, UPFC, PST, optimal placement, power injection model.

INTRODUCTION

In recent year, voltage collapse problem has been a basic and important problem to exploit electric power systems[1]. Recent findings report a power system disability to keep voltage constantly, in all disrupted buses. Voltage collapse pointings are known as system loadability edge is known as power level that system collapses before it. Many ways are implemented to identify voltage stability on static analysis techniques based on power flow ways[2]. A simple way to find a system loadability maximum limit is using a common power flow and gradual increasing load near power flow divergence. A power flow Jacobian matrix in power maximum causes to diverge power flow, because of uniqueness. Therefore, continious power flow (CPF) approach is used to over come this problem[3]. Some continious power flow problems are, unconsidering exploitation limitations and also taking a long time algorithm. So, optimal power flow is used to overcome these problems. Optimal power flow is unlinear programming and identifying power system control parameters as if it optimizes a objective function and physical and efficient restrictions imposed by equipment limitations and also, it meets system security limitations. OPF is a main instrument to optimize and design power flow progressively, and it was firstly propounded in 1962 and it took a long time to implement as a efficient and successful algorithm that is useful every day. In[4,5], the procedures offered to resolve OPF in different resources are discused. ON the other hand, developing consume in power systems confront power transition limitation problem. And power flow controllers, such as controlling generators, regulating voltage and condenser banks are not enough to solve this problem. Today, controlling FACTS controllers based on power electronics tools[6], can control power flow with advantage of stabilizing buses voltage level in acceptable limitation, increasing security of system and exploiting near capacity limits, constantly. Thus, a need of an instrument is presented to design power systems with FACTS tools. Taranto in [7], for example, has suggested a method to solve optimal power flow problem including FACTS tools based on linear programs. This procedure can consider series compensatory and phase shifter, but it can't consider lines limitations. In resource[8] is used linear programming based on security limitations to solve OPF and determine FACTS controllers parameters. Chung and Li in[9] have presented a genetic algorithm method to find FACTS tools parameters. In sources[10,11], connecting FACTS and OPF tools algorithm has been used based on Newton's approach, source[12] studies static voltage stability limitation, using HPSO and PSO algorithm methods. In source[13] is discussed, increasing static voltage stability edge using some FACTS elements. THE main purpose of this paper is, providing a method to find and select the best place of setting PST and UPFC elements based on increasing static voltage stability limitation.

In this paper, optimization software named with Generalized Algebraic Modeling System has been used to solve OPF problem and this algorithm is tested on IEEE 118_ bus network.

Upfc Injection Model

A UPFC can be represented in the steady-state by two voltage sources representing basic components of output voltage waveforms of the two converters and impedances being leakage reactances of the two coupling transformers. Figure 1 depict a two voltage-source model of UPFC[14]. Voltage of bus *i* is taken as reference vector, $V_i = V_i \angle 0^0$ and $V_i^{'} = V_{se} + V_i$ The voltage sources, V_{se} and V_{sh} ,are controllable in both their magnitudes and phase angles. V_{se} could be defined as:

$$V_{se} = rV_i e^{j\gamma} \tag{1}$$

$0 \le r \le r_{\max}$ and $o \le \gamma \le 2\pi$

The value of r and γ are defined within specified limits given by Equation (1)

The steady-state UPFC mathematical model is developed by replacing voltage source V_{se} by a current source I_{se} parallel with the transmission line, where $b_{se} = 1/X_{se}$

$$I_{se} = -jb_{se}V_{se} \tag{2}$$

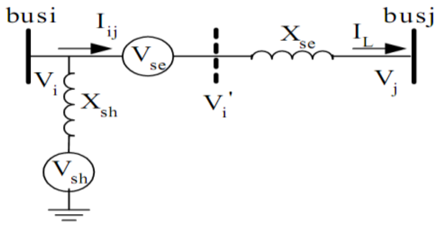

Figure 1. Two voltage-source model of UPFC

The current source I_{se} can be modeled by injection powers at the two auxiliary buses i and j as shown in Figure2.

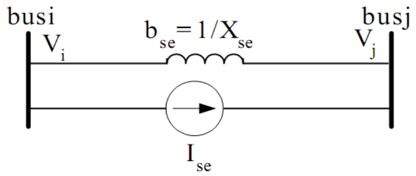

Figure 2. Replacement of series voltage source by a current source.

$$S_{is} = V_i(-I_{se})^* \tag{3}$$

$$S_{js} = V_j(I_{se})^* \tag{4}$$

The injected powers S_{is} and S_{js} can be simplified according to the following operations, by substituting Equation (1) and (2) into Equation (3).

$$S_{is} = V_i(jb_{se}rV_i e^{j\gamma})^* \tag{5}$$

By using the Euler Identity, $(e^{j\gamma} = \cos\gamma + j\sin\gamma)$ Equation (5) takes the form:

$$S_{is} = V_i(e^{-j(\gamma+90)} b_{se} rV_i^{*}) \tag{6}$$

$$S_{is} = V_i^2 b_{se} r[\cos(-\gamma - 90) + j\sin(-\gamma - 90)] \tag{7}$$

By using trigonometric identities, Equation (7) reduces to:

$$S_{is} = -rb_{se}V_i^2 \sin\gamma - jrb_{se}V_i^2 \cos\gamma \tag{8}$$

Equation (6) can be decomposed into its real and imaginary components,

$S_{is} = P_{is} + jQ_{is}$, where

$$P_{is} = -rb_{se}V_i^2 \sin\gamma \tag{9}$$

$$Q_{is} = -rb_{se}V_i^2 \cos\gamma \tag{10}$$

Similar modifications can be applied to Equation (4); the final equation takes the form:

$$\begin{aligned} S_{js} &= V_i V_j b_{se} r \sin(\theta_i - \theta_j + \gamma) \\ &+ jV_i V_j b_{se} r \cos(\theta_i - \theta_j + \gamma) \end{aligned} \tag{11}$$

Equation (11) can also be decomposed into its real and imaginary parts,

$S_{is} = P_{is} + jQ_{is}$, where

$$P_{js} = V_i V_j b_{se} r \sin(\theta_i - \theta_j + \gamma) \tag{12}$$

$$Q_{js} = jV_i V_j b_{se} r \cos(\theta_i - \theta_j + \gamma) \tag{13}$$

Based on Equations (9), (10), (12), and (13), the power injection model of the series connected voltage source can be seen as two dependent power injections at auxiliary buses *i* and *j*, as shown in Figure 3[15,16].

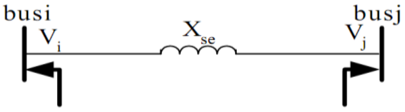

Figure 3. Equivalent power injections of series branch.

The apparent power supplied by the series converter is calculated as.

$$S_{series} = V_{se} I_{ij}^* = re^{j\gamma} V_i \left(\frac{V_i' - V_j}{jX_{se}} \right)^* \tag{14}$$

.

Active and reactive power supplied by the series converter can be calculated from Equation (14):

$$S_{series} = re^{j\gamma}((re^{j\gamma}V_i + V_i - V_j)/jX_{se})^* \tag{15}$$

$$S_{series} = rV_i e^{j(\theta_i + \gamma)}((rV_i e^{-j(\theta_i + \gamma)} + V_i e^{-j\theta_i} - V_j e^{-j\theta_j})/- jX_{se}) \tag{16}$$

$$S_{series} = jb_{se} r^2 V_i^2 + jb_{se} rV_i^2 e^{j\gamma} - jb_{se} V_i V_j e^{j(\theta_i - \theta_j + \gamma)} \tag{17}$$

$$\begin{aligned} S_{series} &= jb_{se} r^2 V_i^2 + jb_{se} rV_i^2 (\cos\gamma + j\sin\gamma) \\ &- jb_{se} V_i V_j (\cos(\theta_i - \theta_j + \gamma)) + j\sin(\theta_i - \theta_j + \gamma) \end{aligned} \tag{18}$$

The final form of Equation (19) can be written as:
$S_{series} = P_{series} + jQ_{series}$, where:

$$P_{series} = rb_{se} V_i V_j \sin(\theta_i - \theta_j + \gamma) - rb_{se} V_i^2 \sin\gamma \tag{19}$$

$$Q_{series} = -rb_{se} V_i V_j \cos(\theta_i - \theta_j + \gamma) + rb_{se} V_i^2 \cos\gamma + r^2 b_{se} V_i^2 \tag{20}$$

The reactive power delivered or absorbed by converter 1 is not considered in this model, but its effect can be modeled as a separate controllable shunt reactive source. In this case the main function of reactive power is to maintain the voltage level at bus *I* within acceptable limits. In view of the above explanations, Q_{shunt} can be assumed to be *0*. Consequently, steady-state UPFC mathematical model is constructed from the series connected voltage source model with the addition of a power injection equivalent to $P_{shunt} + j0$ to bus I, as depicted in Figure 4.

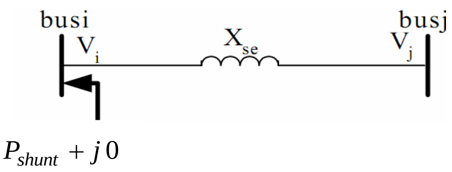

Figure 4. Equivalent power injection of shunt branch.

Finally, steady-state UPFC mathematical model can be constructed by combining the series and shunt power injections at both bus *I* and bus *j* as shown in Figure 5.

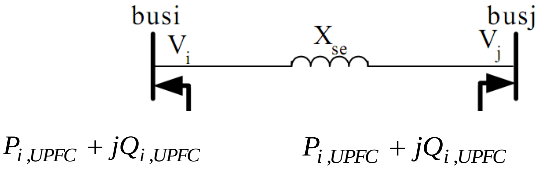

Figure 5. Steady-state UPFC mathematical model.

The elements of the equivalent power injections in Figure 5 are,

$$P_{i,upfc} = 0.02 r b_{se} V_i^2 \sin\gamma - 1.02 r b_{se} V_i V_j \sin(\theta_i - \theta_j + \gamma) \quad (21)$$

$$P_{j,upfc} = r b_{se} V_i V_j \sin(\theta_i - \theta_j + \gamma) \quad (22)$$

$$Q_{i,upfc} = -r b_{se} V_i^2 \cos\gamma \quad (23)$$

$$Q_{j,upfc} = r b_{se} V_i V_j \cos(\theta_i - \theta_j + \gamma) \quad (24)$$

Pst Injection Model

phase shifter single linear model is shown, considering reactances of dispersing transformers, in figure (6). In this figure, series substrate of phase shifter is modeled as a voltage source and the value is stated as follow[17]:

$$V_B = k e^{j\varphi} V_E \quad (25)$$

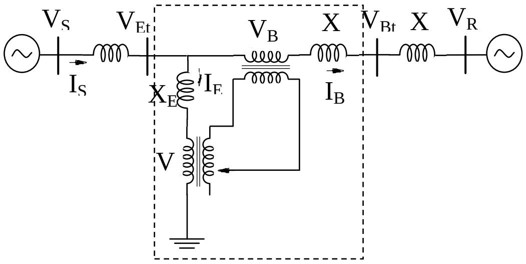

Figure6. phase shifter single linear model

Parallel substrate of phase shifter is modeled by Z_V and X_P and a voltage V_R source that it is receiving bus voltage. Using figure(6) and changing, linear criptic voltage sources to parallel flow source with these lines, PST power injection model is obtained, based on figure(7). $P_{i,PST}$ and $Q_{i,PST}$ are injection active and reactive powers to ith bus respectively, and $P_{j,PST}$ and $Q_{j,PST}$ are injection active and reactive powers to jth bus respectively.

$$P_{i,PST} = -b_{se}kV_iV_j \sin(\delta + \sigma) \tag{26}$$

$$P_{j,PST} = -P_{i,PST} \tag{27}$$

$$Q_{i,PST} = -b_{se}V_i^2k^2 - 2b_{se}kV_i^2\cos(\sigma) + b_{se}kV_iV_j\cos(\delta + \sigma) \tag{28}$$

$$Q_{j,PST} = b_{se}kV_iV_j\cos(\delta + \sigma) \tag{29}$$

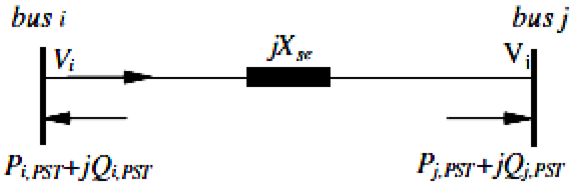

Figure7 . PST power injection model

Problem Formulation

Set up FACTS elements have adventages such as preventing over load, reduce losses and decrease cost of generator, increase a system loadability and etc in power systems. It's possible that each of these characteristics are selected as a objective function with FACTS element for OPF problem. In this paper, a system loadability factor is selected as a goal to assess a static voltage stability edge.

A. Objective function

To obtain a system loadability maximum(static voltage stability limit), a system loadability factor (λ) is used as a objective function of problem[18].

$$F = \lambda \tag{30}$$

B. Conditions and limitation of problem

Problem conditions are parallelism and unequal functions that it's necessary to be supplied in optimal response searching process.

Parallelism restrictions

Parallelism restrictions are similar to parallelism equations of active and reactive powers used in normal power flow of same power floes without FACTS tools. These conditions are those equations of power flow with Newton's Raphson's, Gous saydel's method that are stated as follow:

$$P_{Gi} = P_{Di} + \sum_{j=1}^{NB} |V_i|\,|V_j|\,|Y_{ij}|\cos(\delta_{ij} - \theta_{ij}) \tag{31}$$

$$i = 1, \ldots, NB$$

$$Q_{Gi} = Q_{Di} + \sum_{j=1}^{NB} |V_i|\,|V_j|\,|Y_{ij}|\sin(\delta_{ij} - \theta_{ij}) \tag{32}$$

$$i = 1, \ldots, NB$$

$$\widehat{P}_{Gi} = \widehat{P}_{Di} + \sum_{j=1}^{NB} |\widehat{V}_i|\,|\widehat{V}_j|\,|Y_{ij}|\cos(\widehat{\delta}_{ij} - \theta_{ij}) \tag{33}$$

$$i = 1, \ldots, NB$$

$$\widehat{Q}_{Gi} = \widehat{Q}_{Di} + \sum_{j=1}^{NB} |\widehat{V}_i|\,|\widehat{V}_j|\,|Y_{ij}|\sin(\widehat{\delta}_{ij} - \theta_{ij}) \tag{34}$$

$$i = 1, \ldots, NB$$

$$\widehat{P}_{Di} = (1+\lambda)\, P_{Di} \tag{35}$$

$$\widehat{Q}_{Di} = (1+\lambda)\, Q_{Di} \tag{36}$$

$$\sum_{j=1}^{NB} \widehat{P}_{Gi} = (1+\lambda+k_G) \sum_{j=1}^{NB} P_{Gi} \tag{37}$$

NB: The number of system buses,

$\widehat{Q}_{Gi}$ *and* $\widehat{P}_{Gi}$ *and* Q_{Gi} *and* P_{Gi} : Productive active and reactive powers in ith bus.

Q_{Di} *and* P_{Di} : Demanded active and reactive powers in ith bus.

$\widehat{V}_i$ *and* $\widehat{\delta}_i$ *and* V_i *and* δ_i **:** voltage magnitiude and voltage phase angle of ith bus.

$\widehat{V}_j$ *and* $\widehat{\delta}_j$ *and* V_j *and* δ_j : voltage magnitiude and voltage phase angle of jth bus.

In above equations, variables with superscript (^) are relaited to a system critical point. As mentioned before, we have used power injection model of these elements to add FACTS elements with OPF problem. FACTS elements inject active and reactive power to each of linear first and final buses connected to it. Thus, relations of (31), (32), (33), (34) change, considering these injection powers to power system, as follow:

$$P_{Gi} + P_{FACTS_i} = P_{Di} + \sum_{j=1}^{NB} |V_i|\,|V_j|\,|Y_{ij}| \cos(\delta_{ij} - \theta_{ij}) \qquad i = 1, \ldots, NB \tag{38}$$

$$Q_{Gi} + Q_{FACTS_i} = Q_{Di} + \sum_{j=1}^{NB} |V_i|\,|V_j|\,|Y_{ij}| \sin(\delta_{ij} - \theta_{ij}) \qquad i = 1, \ldots, NB \tag{39}$$

$$\widehat{P}_{Gi} + \widehat{P}_{FACTS_i} = \widehat{P}_{Di} + \sum_{j=1}^{NB} |\widehat{V}_i|\,|\widehat{V}_j|\,|Y_{ij}| \cos(\widehat{\delta}_{ij} - \theta_{ij}) \qquad i = 1, \ldots, NB \tag{40}$$

$$\widehat{Q}_{Gi} + \widehat{Q}_{FACTS_i} = \widehat{Q}_{Di} + \sum_{j=1}^{NB} |\widehat{V}_i|\,|\widehat{V}_j|\,|Y_{ij}| \sin(\widehat{\delta}_{ij} - \theta_{ij}) \qquad i = 1, \ldots, NB \tag{41}$$

Unequal restrictions

Unequal restrictions used to implement proposed algorithm include these cases:

$$\lambda \ge 0 \tag{42}$$

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \tag{43}$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \tag{44}$$

$$P_{Gi}^{\min} \le \widehat{P}_{Gi} \le P_{Gi}^{\max} \tag{45}$$

$$Q_{Gi}^{\min} \le \widehat{Q}_{Gi} \le Q_{Gi}^{\max} \tag{46}$$

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{47}$$

$$V_i^{\min} \le \widehat{V}_i \le V_i^{\max} \tag{48}$$

$$|S_{ij}| \le S_{ij}^{\max} \tag{49}$$

Equation(49) is related to lines transferable power.

PST and UPFC elements limitation: Permissible limit relevant to element controllable parameter is as follow:

UPFC variables limitation:

$$0 \le r \le 1,\ -180^\circ \le \gamma \le 180^\circ$$

PST variable limit:

$$-20^\circ \le \sigma \le 20^\circ$$

Implementing Proposed Approach

In this section, proposed approach is implemented on IEE 118_ bus network. IEEE network is used to show effect of PST and UPFC to improve static voltage stability edge, here. Optimizing the objective function accomplishs in two stages, in first stage, the objective function is optimized without set up FACTS element and percent of increasing system loadability (static voltage stability limit) is obtained, and in the next stage, the effect of set up PST and UPFC elements on static voltage stability edge is reveald. In this paper, two softwares GAMS and MATLAB are used to find placement of FACTS elements. GAMS software acts as a mediator that receives the data of network after preparing by MATLAB software, and it considers to solve OPF problem. Flow chart of proposed approach is shown in figure(8).

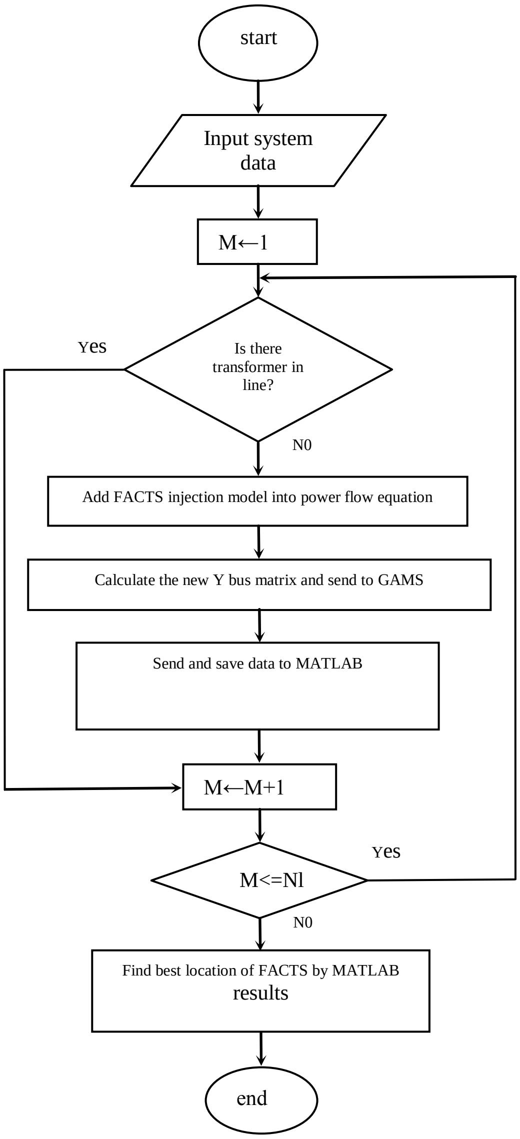

Figure8. Flow chart of the proposed algorithm

IEEE 118_ bus network

This network has 118 buses, 186 lines and 54 generators. In this network maximum load power is, 4242 megawatts and maximum production is, 9966.2 megawatts, that it's selected to show ability and velocity of proposed algorithm for OPF in larg networks. As shown in table1, the value of increasing permissible load for 118_ bus network without employing FACTS elements is 0.98795 and maximum loadability is 1.24959 between buses 76, 77 instead of set up PST in all lines, and also 1.2591 between buses 77, 80 instead of set up UPFC in all lines.

Table 1. Results of ieee 118- bus system

FACTS PARAMETERS	location)bus-bus(	Load ability	
-	-	98.795	Without FACTS
$0.2706\sigma^{o}=.$	77-76	1.24959	With PST
$r=0.4677$ $115.3274\gamma^{o}=$	80-77	1.2591	With UPFC

CONCLUTIONS

So far, the most approachs are presented to find placement of FACTS tools, are limited to small systems, and it needs long time to calculate.

In this paper is used two softwares GAMS and MATLAB for placement. Results suggest preference UPFC in maximizing system load ability than PST.

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