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Unified Power Flow Controller On Transmission Lines using Fault Location Algorithm

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Abstract

In this paper, a new fault location method on transmission lines using power flow controller is proposed. This method uses synchronous data gathered from both ends of the transmission line that is voltage and current and takes advantages of the distributed parameter line model in time domain. One quadratic equation is obtained, assuming that the fault is located on the left-hand side of the UPFC. The same procedure is applied for the assumed fault on the right-hand side of the UPFC and another quadratic equation is achieved. These two equations are used to derive an optimization problem that the location of fault is calculated by solving this problem. The fault can be evaluated in transmission line for a particular distance, including a UPFC simulated in MATLAB/Simulink, has been used to evaluate the performance of the new method. The obtained results show the accuracy of the proposed algorithm.

Index Terms— distributed parameter line model, Fault diagnosis, optimization, Power distribution faults, unified power-flow controller (UPFC).

1. Introduction

Rapid grow of power system grids during last years caused an increase in both the number of lines and their total length. Along with power energy consumption rise, a continuous and reliable energy supply is demanded. Transmission lines are essential parts of a power system for power energy delivery from generating plants to end customers. They are a part of the system where faults occur most likely. These faults result mostly from mechanical failures and have to be removed before re-energization of the line. Accurate fault location is highly required by operators and utility staff to expedite service restoration, reduces outage time, operating costs and customer complains. Fault location is still the subject of rapid further developments. Research efforts are focused on developing efficient fault location algorithms intended for application to more and more complex networks.

UPFC is a combination of STATCOM and a SSSC which are coupled via a common dc link to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC, by means of angularly unconstrained series voltage injection, is able to control, concurrently or selectively, the transmission line voltage, impedance, and angle or, alternatively, the real and reactive power flow in the line. The UPFC may also provide independently controllable shunt reactive compensation.

2. Proposed Fault location method

Fig. 1 shows a transmission line including a UPFC in which assuming that a three-phase fault occurs on the left-hand side of the UPFC at point F, at a distance x from the sending end. Systems A and B represent Thevenin's equivalent of the external networks.

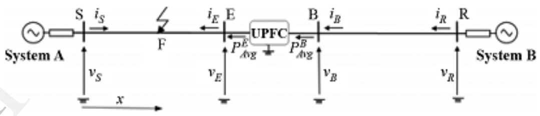

Fig. 1. Single-line diagram of transmission line including UPFC. The fault occurs on the left-hand side of the UPFC.

S and R represent sending and receiving end buses, respectively. Since the BR section of the line is active, the voltage and current vectors at the right-hand side of the UPFC (V_B,I_B) can be calculated using the receiving end voltage and current vectors (V_R,I_R). For the faulty section of the line (SE section), the voltage and current vectors of bus S (V_S, IS) are known and the voltage and current of bus E (V_E, IE) are to be determine. Therefore, it is not possible to use two-terminal fault-location methods to locate the fault on the transmission line, unless by utilizing the model of the UPFC [6]. By using the same procedure, the voltage and current of bus E are calculated by using the obtained data of bus B that inserts inherent errors in the fault-location algorithm which are related to the UPFC model. In this paper, the presented method uses the known data to find the fault location and does not need to know the UPFC parameters, but uses the average power flow through the UPFC to find the fault location.

Thus, consider the average power of bus B (P^E_{Avg}). Which is shown in Fig.1. It can be calculated by using the voltage and current vectors of bus B(V_B,i_B) can be obtained as follows:

$$P^E_{Avg}(t) = P^B_{Avg}(t) - \Delta p(t) \tag{1}$$

where

ΔP absorbed or generated or lost average power by the UPFC.

Δp(t) depends on the UPFC operational characteristics and its controller system performance. Thus, Δp(t) is related to the UPFC modelling but, it is negligible compared with P^B_{Avg}(t).By ignoring Δp(t) , P^E_{Avg}(t) is determined by means of and the fault-location method will be independent of the UPFC Δp(t) model. In Section III-C. it will be seen that ignoring has no considerable effect on the results of the fault-location algorithm.

In this paper, the proposed algorithm uses the voltage and current of bus S and the average power of bus E to find the location of fault which is described in the following subsections.

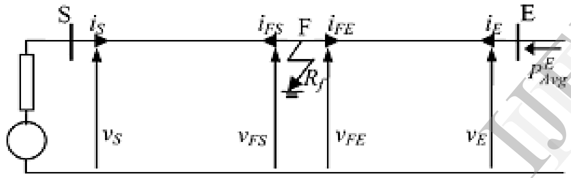

Fig. 2. Single-line diagram of the SE section of the transmission line with distributed parameters.

When the fault occurs on the right-hand side of the UPFC, the same procedure is performed. At first, the basic principle of the proposed algorithm is described via the SE part of the transmission line for a symmetrical three-phase fault in the next subsection. Then, this algorithm is developed for the transmission line including the UPFC.

Hitherto, an important part of the proposed method is described via the SE section of the line assuming that the sending end voltage an d current vectors and the average power of bus E are known and available. This part of the method is subsequently used to develop the fault-location algorithm for transmission lines including the UPFC.

2.1. Transmission Lines Including UPFC

Since the location of fault with respect to the UPFC location is unknown prior to estimation of the fault location, three steps are considered to describe the method. In the first and second steps, it is assumed that the fault is located on the left- and right-hand side of the UPFC, respectively. Two quadratic equations with respect to the first two steps are obtained, which are finally used to derive an optimization problem in the third step. The correct location of fault is achieved by solving the obtained optimization problem. These steps are illustrated as follows.

Step 1) In this step, it is assumed that a three-phase fault occurs on the left-hand side of the UPFC (as shown in Fig. 1). Thus, the described procedure in Section II-A can be utilized. The BR section of the line is sound. So the voltage and current vectors at the right-hand side of the UPFC (V_B,i_B) can be obtained by using the receiving end voltage and current vectors (V_R,i_R).

$$V_B(t) = g_2(V_R, i_R, t) \tag{2}$$

$$i_B(t) = f_2(V_R, i_R, t) \tag{3}$$

Based on (1) and ignoring Δp(t), the average power of bus E($P^{(k)}_{Avg}$(t)) is equal to which is defined as follows:

$$P^B_{Avg}(t) = \frac{1}{T}\int_{t-T}^{t}[V_B(t_1)']'.i_B(t_1).dt_1 \tag{4}$$

Step 2) In this step, it is assumed that the fault is located on the right-hand side of the UPFC and the SE section of the line is sound. The voltage and current vectors at the left-hand side of the UPFC(V_E,i_E) can be obtained by using the sending end voltage and current vectors (V_S,i_S). So the following equations can be expressed like (2) and (3):

$$V_E(t) = g_3(V_S, i_S, t) \tag{5}$$

$$i_E(t) = f_3(V_S, i_S, t) \tag{6}$$

By ignoring Δp in (1), the average power of bus B((P^B_{Avg})(t)) is equal to ((P^E_{Avg})(t)). Considering the BR part of the line, the average power of bus B ((P^B_{Avg})(t)) is known and the voltage and current vectors of bus R are available. Therefore, the described procedure in Section II-A can be employed again.

Step 3) double-criterion function (7) is defined, which are obtained in the first and second steps

$$H=\begin{cases} H_1(V_S,i_S,V_R,i_R,x,R_f,t) & 0<x<x_{SE} \\ H_2(V_S,i_S,V_R,i_R,x,R_f,t) & x_{SE}<x<x_{SR} \end{cases} \tag{7}$$

Function (7) is valid for all points of the line from the beginning to the end, except for the UPFC location. But just at the true fault point and for the true fault resistance, function (7) is equal to zero during the fault occurrence.

$$\begin{cases} H(V_S,i_S,V_R,i_R,x,R_f,t)=0 \\ 0<x<x_{SR} \\ X\neq x_{SE} \end{cases} \tag{8}$$

In (8), only two unknown variables exist: the fault distance from the sending end (x) and the fault resistance (R_f).To find the location and resistance of the fault, at first (8) is discretized.

$$\begin{cases} H(V_S,i_S,V_R,i_R,x,R_f,n)=0 \\ 0<x<x_{SR} \\ X\neq x_{SE} \end{cases} \tag{9}$$

Where

n, Δt=t;

Δt sampling step;

n arbitrary integer.

The samples in the fault interval data window should satisfy this equation. Thus, the fault-location problem is converted to an optimization one and the following optimization problem is expressed based on discretized (9):

$$\{\mathrm{Min}(x, R_f)=\mathrm{Min}\Sigma_n H(V_S,i_S,V_R,i_R,x,R_f,n)$$

$$\text{Subject to:}\begin{cases} 0\leq R_f \\ 0<x<x_{SR} \\ X\neq x_{SE} \end{cases} \tag{10}$$

Since the fault resistance is a positive number, the constraint $R_f \leq 0$ is added to the optimization problem. Solving optimization problem (10) [11], it offers the solution (x_F, RF), where x_F is the obtained location of fault and R_F is the obtained fault resistance. Therefore, the location of fault and the correct side of it are determined simultaneously.

3. Testing and Evaluating

3.1. Studied System

A 300-km, 500-kV transmission line including a UPFC (shown in Fig. 1) was simulated in MATLAB /Simulink to evaluate the accuracy of the proposed algorithm. For the simulation study, the UPFC consists of two 200-MVA, three-level, 48-pulse voltage-source inverters which are connected through two 5000- μF capacitors as the dc link. The shunt inverter is connected to the transmission line through four 125/15-kV zigzag transformers and regulates the voltage at its point of connection to V_{ref}, during steady-state operating conditions by controlling the absorbed or generated reactive power to the system, while also allowing active power transfer to the series converter through the dc link. Another inverter is connected to the transmission line through four 12.5/12.5-kV
Zigzag transformers to regulate the active and reactive power flow through the transmission line.

3.2. Control System of the UPFC

Two parts are considered Where model the control system of the UPFC for simulation in MATLAB/Simulink: the STATCOM control part and SSSC control part. The three-phase voltages at the STATCOM connecting point are sent to the phase-locked loop (PLL) to calculate the reference angle which is synchronized to the phase A voltage.

In the STATCOM control part, the three-phase shunt currents are decomposed into their real component I_d and reactive component I_q via the abc –dqo transformation using the PLL angle as reference. The magnitude of the positive-sequence part of the connecting point voltage is compared with the reference voltage V_{ref} , and the error is passed through a proportional-integral (PI) controller to produce the reference reactive current I_{qref}. This current reference is compared with the reactive part of the shunt current to produce the error which will be passed through another PI controller to obtain the relative phase angle of the inverter voltage with respect to the phase A voltage. The phase angle, along with the PLL signal, is fed to the STATCOM firing pulse generator to generate the desired pulse for the voltage-source inverter.

For the SSSC, the series-injected voltage is determined by a closed-loop control system to ensure that the desired active and reactive powers flowing in the transmission line are maintained. The three-phase voltages and currents of bus B are decomposed into their direct and quadrature components via the abc-qdo transformation using the PLL angle as reference. The direct and quadrature components of the voltage of bus B, together with the desired P_{ref} and Qr_{ef}, are used to compute the desired real and reactive components of the line current(I_{prefL},I_{qref}). These current references are compared with the active and reactive components of the line current to produce the errors which will be passed through two PI controllers to obtain the direct and quadrature components of the series converter voltage(V_d and V_q), respectively.

The magnitude and phase angle of the series converter voltage can be obtained by a rectangular to polar transformation of V_d and V_p components. The phase angle and dead angle (calculated using the relationship between the inverter voltage and the dc-link voltage), along with the PLL signal, are fed to the SSSC firing pulse generator to generate the desired pulse for the SSSC voltage-source inverter.

4. Conclusion

The proposed method provides the fault location on transmission lines by using unified power flow controller. The proposed method is composed of three steps. In the first two steps, assuming that the fault is located on the left- and right-hand side of the UPFC , two quadratic equations are obtained which are used to derive the optimization problem in the third step. The side and location of the fault and its resistance are determined simultaneously by solving this optimization problem; thus, the algorithm does not need to propose a selector. Also, the proposed method does not use the model of the UPFC for the fault location. So the accuracy of the proposed fault-location algorithm is not under influence of the UPFC modelling.

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