Active and reactive power compensation through a preventive defense strategy based on FACTS devices

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Abstract—The excessive increase in the number of subscribers in the electrical grid requires a flexible control of this electrical network and a better reliability of the offered power quality. Thus, several defense plans are omnipresent to ensure stability, continuity of service and to overcome some disturbances which can affect the electrical grid. In this context, we present in this paper the development of a new control strategy used a compensator UPFC based on fuzzy controllers. We simulated this strategy in the IEEE test 14 buses network and the results were promising.

Index Terms—FACTS, UPFC, NSRF Fuzzy logic, PSRF, PWM, positive sequence, negative sequence.

I. INTRODUCTION

Several disturbances can occur after transport of active and reactive power over long distances. In this context, considering the complexity of electrical grid, the participation of the generators in the production of energy has become insufficient. It is generated by the compensating devices in order to ensure stability and to provide a voltage level as regular as possible and this through means of compensation commonly designated by FACTS (Flexible AC Transmission Systems). Indeed, recent studies developed based on this compensator have established new control strategies to ensure continuity of service and guarantee a better quality of energy produced.

In this context, Eskandar Gholipour [1] was based on a mathematical model of the UPFC compensator in order to compensate the reactive power required by the electrical grid. In this model, Gholipour has separated the parallel part (STATCOM) into two parts: One part considered as a controllable susceptance \( b_q \) in order to control active and reactive power indirectly and another part considered as a current generator responsible for controlling the incoming and outgoing active powers of the UPFC and to studying the contribution of the UPFC compensator on improving the transient stability. This was further reinforced by a study of the impact of the static compensator location on grid stability. The most efficient configuration of the UPFC is in the middle of the line seen its participation to increase the level of reactive power and to stabilize the electrical grid during disturbances mode. But there is always the problem of the first oscillation damping. Moreover, it should be noted that the strategies did not take into account the level of the voltage across the UPFC which has exceeded its nominal value for a short time. By contrast, other works [2], [3] has considered these deficiencies and has proposed a new interface of the UPFC based on PST device (Power System Toolbox) of the MATLAB environment to mitigate power oscillations and to ensure the power system stability. Indeed, they have adopted a DC-link voltage control by influencing on the firing angle of the switches and the modulation index in order to control the voltage where the UPFC is integrated. The strategy was effective, but the technique of modulation adopted for the converters is deficient in the case of high power applications.

In addition, in order to inquire about the control techniques’ of the static compensator, Kalyani and Das G.Tulasiram [4] have developed a model of UPFC in which they have adopted the automatic control of the voltage level.

Mentioned works present deficiencies especially in the case of fault qualified as severe occurrence. This inspires us to propose a new strategy that takes into account the stability guarantee and the continuity of service even in the event of fault occurrence.

II. STUDY OF THE SYSTEM IN THE DISTURBED MODE

During the disturbed mode, static compensators contribute to the release of steady-state of the voltage levels affected and this through a controlled exchange between the converters and the buses to which they are connected.

In perturbed mode, the static compensators contribute to the delivery for the stable state of the levels of the affected voltages and it by means of a controlled exchange, between these converters and the buses which they are connected. Based on the equation of the voltage drop between two buses \( j \) and \( k \) expressed as follows:

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\[
\Delta V_j = \frac{R_L}{V_j}P_j + \frac{X_L}{V_j}Q_j
\]  
(1)

With:
\[
\begin{align*}
P_j &= Y_LV_j^2 \cos(\theta_j) - Y_LV_jV_s \cos(\theta_j - \alpha_k - \theta_L) \\
Q_j &= -Y_LV_j^2 \sin(\theta_j) - Y_LV_sV_s \sin(\theta_j - \alpha_k - \theta_L)
\end{align*}
\]  
(2)

Voltage levels at different buses undergo changes during the occurrence of such default, which can lead to a call of active and reactive power (equation (1)). Under these conditions, the UPFC contributes to compensate these powers to restore the voltage levels. This compensation is effected through the injection, by UPFC, of a voltage \(sV\) to restore the voltage levels. This compensation is effected under the occurrence of such default, which can lead to a call of powers requested by the network after the fault occurrence. This strategy was supported by the integration of two fuzzy algorithms of control taking into account variables which fluctuate at the double of the studied network frequency [5].

During the phase of disturbance appearance, the injected powers are affected with oscillations with terms fluctuating at the double of the studied network frequency [5].

This results from the fact that any electric quantity \(x\) (currents or voltages), considered in a positive synchronous reference frame (PSRF) turning with the pulsation \(+\omega_L\), or negative synchronous reference frame (NSRF) turning with the pulsation \(-\omega_L\), is not other than the sum of a constant term, materialized by the components of \((d, q)\) axes of the positive sequence \((x_{dp}^+, x_{qp}^+)\) to which come to superimpose terms fluctuating with the double of the network frequency, materialized by the components of \((d, q)\) axes of the negative sequence \((x_{dn}^+, x_{qn}^+)\) [5]:

\[
\begin{align*}
x_d^+ &= x_{dp}^+ + x_{dn}^+ \cos(2\theta) + x_{qn}^+ \sin(2\theta) \\
x_q^+ &= x_{dp}^+ - x_{dn}^+ \sin(2\theta) + x_{qn}^+ \cos(2\theta)
\end{align*}
\]  
(4)

Based on the expression of the power:

\[
\bar{S}_j = \bar{V}_j \bar{I}_j
\]  
(5)

Relatively to the positive synchronous reference frame (RSP), the relation (5) becomes:

\[
\bar{S}_j = \bar{V}_j \bar{I}_j^*
\]  
(5)

Taking account of (4), the active and reactive powers are expressed as follow:

\[
\begin{align*}
P_j &= P_o + P_{2f} \\
Q_j &= Q_o + Q_{2f}
\end{align*}
\]  
(7)

Where:
\(P_o\) and \(Q_o\) are functions of the \((d, q)\) axes of the positive sequences of the currents and voltages \((x_{dp}^+, x_{qp}^+)\) at the same bus. \(P_{2f}\) and \(Q_{2f}\) are functions of the \((d, q)\) axes of the negative sequences of the currents and voltages \((x_{dn}^+, x_{qn}^+)\).

The terms \(P_j\) and \(Q_j\) expressed by the relation (8) must be dynamic references to the UPFC. Hence, to establish the algorithms of control taking into account variables which fluctuate at the double of the studied network frequency, we develop in what follows a new control strategy of the UPFC compensator taking into account potential changes in levels of active and reactive power in all network buses.

This strategy was supported by the integration of two fuzzy controllers to optimize the amount of active and reactive powers requested by the network after the fault occurrence. This strategy has been tested on the network test IEEE 14 buses.

### III. DEFENSE STRATEGY

#### A. Introduction

In order to have an optimized compensation of power able to drive the network to a stable state, we present the adopted strategy implemented in the electrical grid as shown in the following figure:
Indeed, we have evaluated, for each fuzzy controller, the sum of active or reactive power injected at different buses \( \sum_{k=2}^{k=N} P_k, \sum_{k=2}^{k=N} Q_k \) that will be compared instantaneously with the reference value \( \sum_{k=2}^{k=N} P_k^*, \sum_{k=2}^{k=N} Q_k^* \) determined before appearance of a given fault.

As we already mentioned and in the presence of a disturbed mode, the active and reactive powers contain fluctuating components with the double of the studied network frequency, thus the total of active and reactive powers to control is such as:

\[
\begin{align*}
\sum_{k=2}^{k=N} P_k &= \sum_{k=2}^{k=N} P_{k0} + k \sum_{k=2}^{k=N} P_{k2f} \\
\sum_{k=2}^{k=N} Q_k &= \sum_{k=2}^{k=N} Q_{k0} + k \sum_{k=2}^{k=N} Q_{k2f}
\end{align*}
\]

(9)

The use of the fuzzy controller (see Fig. 1) in the algorithms for the evaluation active power and reactive reference \( P_{UPFC}^* \) and \( Q_{UPFC}^* \) seems interesting. This is due to the dynamic adaptation of this type of controller to pursue the amplitude of the variables to be controlled.

### B. Active and reactive power Estimation

The estimation of the active and reactive power quantities to be compensated by the UPFC is performed through two fuzzy controllers; one is designated for the estimation of the amount of active power (fuzzy controller II) and the other is reserved to the reactive power estimation (fuzzy controller I).

Each fuzzy corrector treats two inputs \( (\delta, \dot{\delta}, \ddot{\delta}) \). The first input is materialized by the difference between the amplitudes of the active or reactive powers injected at each bus before and during the fault.

\[
\begin{align*}
\varepsilon_1 &= \sum_{k=2}^{k=N} [Q_k^* - Q_k] \\
\varepsilon_2 &= \sum_{k=2}^{k=N} [P_k^* - P_k]
\end{align*}
\]

(10)

The second input for each controller represents the variation of this difference on a calculation step \( \varepsilon_{n+1} - \varepsilon_n \). Furthermore, the output of the fuzzy controller (I) is a command vector similar to the amount of reactive power \( Q_{UPFC}^* \) required by the electrical grid.

While the second controller (II) generates a command vector similar to the amount of active power to be compensated \( P_{UPFC}^* \).

We point out that to treat numerical linguistic variables, the use of some membership functions is essential [5]. We can characterize these variables by fuzzy sets of the type “negative small (NS)”, “negative great (NG)”, “negative medium (NM)”, “zero (ZE)”, “positive small (PP)”, “positive medium (PM)”, “positive great (PG)”, etc. Several membership functions can be associated to these fuzzy sets.

#### TABLE I. FUZZY DEDUCTIONS FOR FUZZY CONTROLLER I

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#### TABLE II. FUZZY DEDUCTIONS FOR FUZZY CONTROLLER II

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The fuzzy decision-making of each corrector is based on three data processing runs of the variables to control. A first data processing run consists of a fuzzification, in one second phase the corrector deduces the fuzzy inferences according to imposed conditions and in a third phase of calculation; each corrector applies a method of defuzzification to deduce a non fuzzy vector of command. The method used in order to evaluate this vector, consists in determining the X-coordinate of the centre of gravity of the surface swept by the fuzzy deductions.

\[
\begin{align*}
    u_1^* &= \frac{1}{\mu \left( u_1 \right)} - \int u_1 \mu \left( u_1 \right) \, du_1 \\
    &= Q_{UPFC} \\
    u_2^* &= \frac{1}{\mu \left( u_2 \right)} - \int u_2 \mu \left( u_2 \right) \, du_2 \\
    &= P_{UPFC}
\end{align*}
\]

(11)

IV. SIMULATIONS AND RESULTS

The adopted strategy based on UPFC compensator was applied to the network test IEEE 14 buses 5 machines \((615 \text{ MVA}, 2 \times (25 \text{ MVA}) \text{ and } 2 \times (60 \text{ MVA}))\), (see Fig. 2). To control this type of compensator, we assigned to different loads connected to the studied network, values imposing a nominal operating mode for the five machines such as \(\sum_{i=1}^{5} P_i = \sum_{i=1}^{4} P_{C_i}\).

The simulation of a fault materialized by the opening of the line 4-5 from the moment 62 seconds to 63 seconds in absence of the UPFC connection, showed significant degradation of voltage levels, Figure (3). Under these conditions and for the same type of fault, if the fault takes longer than one second, there would be possibility of collapse phenomenon appearance.

In a second phase, we have simulated the same fault under the same conditions except that we have introduced our new control strategy.

In the presence of the UPFC and for the same fault, we note that the voltage levels have established a new steady state which proves the contribution of the UPFC to guarantee the electrical grid stability.

Referring to Figure 5, we noticed that the amount of active power produced by the machine 4, in absence of the UPFC is greater than in its presence which proves that the UPFC contributes to compensate the deficiency of active power in case of fault.

![Fig. 2. Studied model](image)

![Fig. 3. Voltage at different buses without UPFC](image)

![Fig. 4. Voltage at different buses in presence of UPFC](image)

![Fig. 5. Quantities of active power supplied by the machine-4 (25MVA) - without UPFC](image)

- with and without UPFC
Indeed, based on Figure 6, we found a decrease of the amount of reactive power generated by the machine 4 at the moment we integrate the UPFC. For the same fault, this result justifies the participation of UPFC to provide the optimal rate of reactive power needed for the recovery of voltage levels.

The temporal evolution of the voltages at the terminal of the converter connected to bus 5, figure 7, shows the effectiveness of the adopted strategy.

V. CONCLUSION

In this paper, we presented a preventive strategy of defense based on the implementation of UPFC compensator applied to the network test IEEE 14 buses, in order to ensure compensation of active and reactive power and stabilize eventually the voltage level.

This compensation took place by means of two fuzzy controllers which estimate instantly the active and the reactive power rates requested by the network during the appearance of an event considered as serious. Hence, we have reached a perfect stabilization of the voltage at any bus of the electrical network.

REFERENCES


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