

An Adaptive Neuro-Fuzzy Inference Distributed Power Flow Controller (DPFC) in Multi-Machine Power Systems

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ABSTRACT

A well-prepared abstract enables the reader to identify the basic content of a document quickly and accurately, to determine its relevance to their interests, and thus to decide whether to read the document in its entirety. The Abstract should be informative and completely self-explanatory, provide a clear statement of the problem, the proposed approach or solution, and point out major findings and conclusions. The Abstract should be 100 to 200 words in length. The abstract should be written in the past tense. Standard nomenclature should be used and abbreviations should be avoided. No literature should be cited. The keyword list provides the opportunity to add keywords, used by the indexing and abstracting services, in addition to those already present in the title. Judicious use of keywords may increase the ease with which interested parties can locate our article.

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1. INTRODUCTION

FACTS Technology is concerned with the management of active and reactive power to improve the performance of electrical networks. The concept of FACTS technology [4], [8]-[20] embraces a wide variety of tasks related to both networks and consumers problems, especially related to power quality issues, where a lot of power quality issues can be improved or enhanced with an adequate control of the power flow.

By FACTS, operator governs the phase angle, the voltage profile at certain buses and line impedance. Power flow is controlled and it flows by the control actions using FACTS [4], [8]-[20] devices, which include:

- Static VAR Compensators (SVC)
- Thyristor Controlled Series Capacitors (TCSC)
- Static Compensators (STATCOM)
- Static Series Synchronous Compensators (SSSC)
- Unified Power Flow Controllers (UPFC)

2. UNIFIED POWER FLOW CONTROLLERS (UPFC)

The UPFC may be considered to be constructed of two VSCs sharing a common capacitor on their DC side and a unified control system. A simplified schematic representation of the UPFC is given in Figure 1.

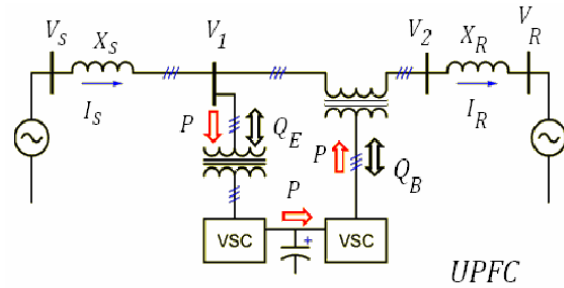


Figure 1. Schematic diagram for the UPFC

The UPFC gives simultaneous control of real and reactive power flow and voltage amplitude at the UPFC terminals. Additionally, the controller may be adjusted to govern one or more of these criteria in any combination or to control none of them. This technique permits with the combined application of controlling the phase angle with controlled series reactive compensations and voltage regulation, but also the real-time change from one mode of compensation into another one to handle the actual system contingencies more effectively. For instance, series reactive compensation may be altered by phase-angle control [2] or vice versa. This can become essentially important at relatively big numbers of FACTS devices will be applied in interconnected power grids, and compatibility and coordination control can own to be save in the face of devices failures and system changes.

2.1. DPFC Modeling

To enable the control of the DPFC [22], controllers for individual DPFC converters are needed. This chapter addresses the basic control system of the DPFC [21], which is composed of shunt control and series control that are highlighted in Figure 2.

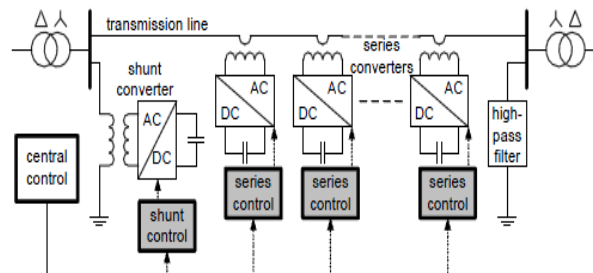


Figure 2 DPFC Basic Control

The functions of the series control can be summarized as:

- Maintain the capacitor DC voltage of its own converter by using the 3rd harmonic frequency components.
- Generate the series voltage at the fundamental frequency that is prescribed by the central control.

The functions of the shunt control are:

- Inject a constant 3rd harmonic current into the line to supply active power for series converters.
- Maintain the capacitor DC voltage of the shunt converter by absorbing active power from the grid at the fundamental frequency.
- Inject reactive voltage at the fundamental frequency [1] to the grid as prescribed by the central control.

To design a DPFC control scheme, the DPFC must first be modeled. This section presents such modeling of the DPFC. As the DPFC serves the power system, the model should describe the behavior of the DPFC at the system level, which is at the fundamental and the 3rd harmonic frequency. The modeling of the switching behavior of converters is not required. The modeling of the DPFC consists of the converter modeling and the network modeling. Due to the use of single-phase series converters, they are modeled as a single-phase system. To ensure that the single-phase series converter model is compatible with the three-

phase network model, the network is modeled as three single-phase networks with 120° phase shift. Figure 3 gives the flow chart of the DPFC modeling process, which leads to six separated models.

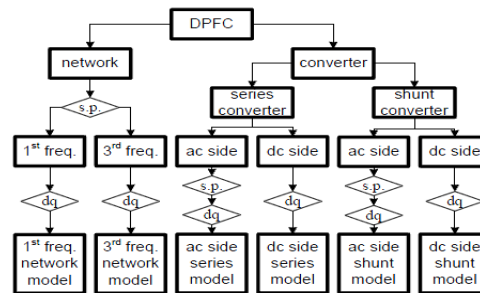


Figure 3. DPFC Modeling process flow chat

Two tools are employed for the DPFC modeling: the superposition theorem and Park's transformation [1]. As is well known, the transmission network is a linear system and the superposition theorem can therefore be applied. However, for the converter, certain approximations are needed for the application of the superposition theorem. Within the flow chart, the diamond shapes with 's.p.' indicate the process of applying the superposition theorem, and the shapes with 'dq' represent the process of Park's transformation. Because Park's transformation is designed for analysis of signals at a single frequency and the DPFC signal consists of two frequency components, the superposition theorem is first used to separate the components. Then, the component at different frequencies are subjected to Park's transformation and analyzed separately. Park's transformation, which is widely used in electrical machinery analysis, transforms AC components into DC.

The principle of Park's transformation is to project the AC signal in vector representation on to a rotating reference frame, referred to as the 'd-q frame'. The frequency of the rotation is chosen to be the same as the frequency of the AC signal. As a result, the voltages and the current in the d-q reference are constant in steady-state. The components at different frequencies are transformed into two independent rotating reference frames at different frequencies. The components at the fundamental frequency are 3-phase components, so Park's transformation can be applied directly. However, as Park's transformation is designed for a 3-phase system, a variation is required before its application to a single-phase system. The reason for this is that the 3rd harmonic component of a three phase system can be considered a single-phase component, as its components are all in phase ('zero-sequence').

2.2. Adaptive Neuro-Fuzzy Inference Systems (ANFIS)

Jang and Sun introduced the adaptive Neuro-Fuzzy inference system. This system makes use of a hybrid-learning rule to optimize the fuzzy system parameters of a first order Sugeno system. The Sugeno fuzzy model (also known as TSK fuzzy model) was presented to save a systematic method to produce fuzzy rules of a certain input-output data set. Figure 4 shows the architecture of two inputs, two-rule first-order ANFIS Sugeno system, the system has only one output.

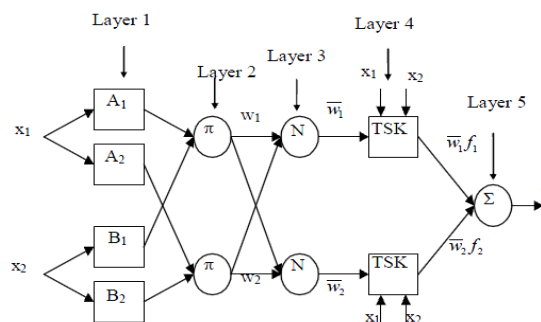


Figure 4. Two-input, two-rule first order Sugeno ANFIS System

The first layer of the ANFIS has adaptive nodes with each node has its function:

$$O_{1,i} = \mu A(x_1), \text{ for } i=1,2 \text{ or } O_{1,i} = \mu B_2(x_2), \text{ for } i=3,4$$

Where x_1 and x_2 are the inputs; and A_i and B_i are linguistic labels for the node. And $O_{1,i}$ is the membership grade of a fuzzy set A ($= A_1, A_2, B_1$ or B_2) to define the degree of applying the input to the set A .

The second layer has fixed nodes, where its output is the product of the present signals to act as the firing power of a rule.

$$O_{2,i} = w_i = \mu A(x_1) \mu B_2(x_2), \text{ for } i=3,4$$

The third layer also has fixed nodes; the i^{th} node computes the ratio of the i^{th} rules firing strength to the rules' firing strengths sum:

$$O_{3,i} = \bar{w}_i = \frac{w_i}{w_1 + w_2}, \quad i=1,2.$$

The nodes of the forth layers are adaptive nodes, each with a node function:

$$O_{4,i} = \bar{w}_i f_i = \bar{w}_i (p_i x_1 + q_i x_2 + r_i)$$

Where w_i is a normalized firing strength produced by layer 3; $\{p_i, q_i, r_i\}$ is the parameter set of the node, and pointed to consequent parameters.

There is a single node in the fifth layer, which is a fixed node, which calculates the resultant output as the summation of all signals.

$$\text{Overall output} = O_{5,1} = \sum_i \bar{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i}$$

The contributions of the paper start with formatting, deriving, coding and programming the network equations required to link DPFC steady-state and dynamic models to the power systems [3]. One of the other contributions of the paper is deriving GA applications on DPFC to achieve real criteria on a real world sub-transmission network. An enhanced GA technique is proposed by enhancing and updating the working phases of the GA including the objective function formulation and computing the fitness using the diversity in the population and selection probability. The simulations and results show the advantages of using the proposed technique. Integrating the results by linking the case studies of the steady-state and the dynamic analysis [5] is achieved. In the dynamic analysis section, a new idea for integrating the GA with ANFIS to be applied on the control action procedure is presented. In addition to, packages of Software for genetic algorithm and adaptive Neuro-fuzzy system are developed. In other related work, GA only was used to enhance the system dynamic performance considering all working range of power system at a time that gave a difficulty and inability in some cases to reach the solution criteria. In this paper, for every operating point GA is used to search for controllers' parameters, parameters found at certain operating point are different from those found at others. ANFISs are required in this case to recognize the appropriate parameters for each operating point.

2.3. Proposed Adaptive Neuro-Fuzzy Inference Distributed Power Flow Controller (DPFC)

The DPFC modeling and control are simulated in the Mat lab Simulink. The schematic of the DPFC system in the simulation is shown in Figure 5. To simplify the calculation, one set of series converters is used to represent the distributed converters.

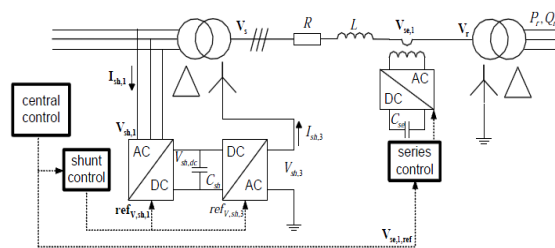


Figure 5. DPFC system in the simulation

The capability of injecting a controllable 360° series voltage is signified by the independent control of the active and reactive power flows at the receiving end. As shown, the active and reactive power can be independently controlled, which indicates that the DPFC is capable of injecting the 360° controllable voltage at the fundamental frequency. The transients are caused by the variation in the DC voltages of the series converters [6]. The DC voltages of both the series and the shunt converters are well maintained during operation. The proposed structure of a DPFC Shunt Converter Control DC voltage regulator is shown in Figure 6.

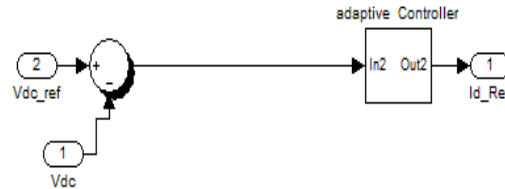


Figure 6. DPFC Shunt Converter Control DC voltage regulator

The proposed structure of Adaptive Neuro-Fuzzy Inference Distributed Power Flow Controller (DPFC) is shown in Figure 7.

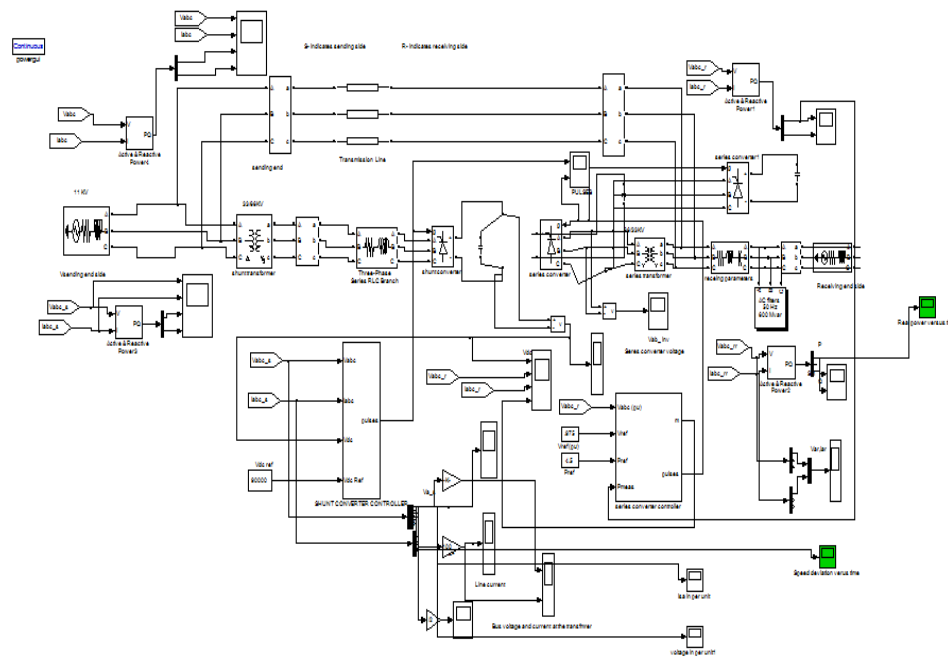


Figure 7. Adaptive Neuro-Fuzzy Inference Distributed Power Flow Controller (DPFC)

3. SIMULATION RESULTS AND DISCUSSIONS

In this section, the DPFC model is created and simulated on Mat lab/Simulink. All the simulations are based on single-phase per-unit system. One shunt converter and two single phase series converters are built and tested.

The system under consideration is simulated under different operating conditions to investigate its transient stability performance and to demonstrate the effectiveness of the proposed controller. The contingency under consideration is a three phase fault at the sending end of one of the transmission lines when the generator is operating at different power levels. The fault is considered to occur between $t=0.2s$ and $t=0.3s$. The fault is cleared with the operation of transmission line reclosure.

The following case studies were undertaken to make the assessments and shown in Figure 8 to Figure 9.

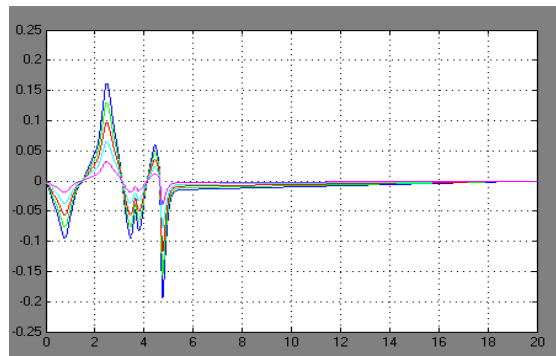


Figure 6-1: Speed deviation versus time

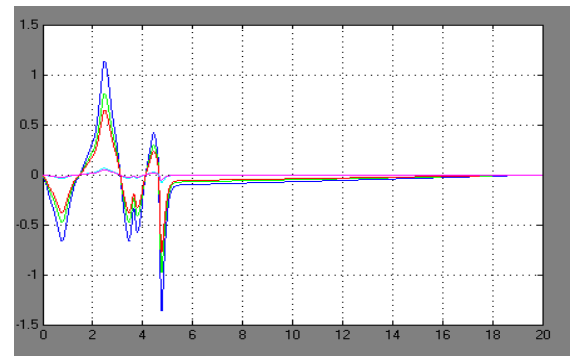


Figure 6-2: Power angle versus time

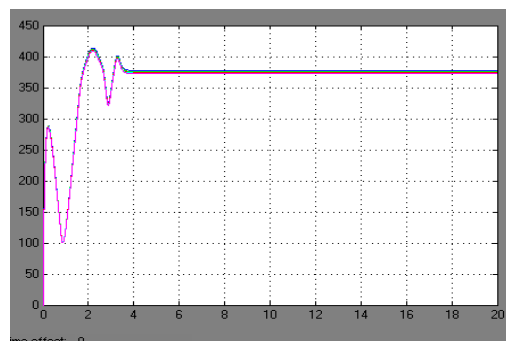


Figure 6-3: Real power versus time

4. CONCLUSION

The DPFC is modeled in the d-q frame by using Park's transformation. The components of the DPFC in AC quantity are transformed into DC quantity. The components in different frequencies are then separately modeled. This model is a good representation of the behavior of the DPFC at the system level and can be used to design the parameters of the DPFC control. Based on the DPFC model, the shunt control and the series control are developed. The functions of these controls are to maintain the DC capacitor voltages of the converters and to ensure the required voltages and currents are injected from the central control. The DPFC basic control and model are simulated in Mat lab Simulink. The simulation results show that the DPFC is able to control the active and reactive power flows independently and that during operation, the DC voltages of the converters are well maintained. Communication between the central control and the series converters is also considered. To increase the reliability of the DPFC during communication failure, the reference signals in DC quantities are used instead of in AC quantities. The line current is selected as the rotation reference frame because it can be easily measured by the series converters without extra cost. During communication failure, the series converter can use the last received setting to continue operation, thereby increasing the system's reliability. This communication method is also tested in Mat lab Simulink. It shows that in steady-state, communication in DC quantities [6]-[7] has the same result as in AC quantities. During communication failure, the series converter of the DPFC can maintain synchronization with the system.

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