# Improvement of Voltage Profile of a Transmission System Using D-Facts

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**Abstract:** *In this paper a Distributed Power flow Controller with different controlling techniques is proposed for the improvement of voltage profile of a load bus in a transmission system. Distributed Power flow Controller (DPFC) is proposed to mitigate power quality problems such as, voltage sag and voltages swell at load bus of four bus power system. To solve these power quality issues different control logics, like PI control and Fuzzy logic control have been proposed. The performance of proposed methods of DPFC with PI control and Fuzzy control are compared using MATLAB/ simulink.*
*Keywords: DPFC, PI Controller, Power Quality, Fuzzy logic controller, Voltage Sag, Voltage Swell.*

## I.    Introduction

Now a day's not only the power engineers but the consumers are also concerned about the quality of electric power. The ultimate reason for interest in power quality studies is its economic value. Industries are relying more on automated equipment to achieve maximum productivity to remain competitive. Thus, an interruption has considerable economic impact. The quality of power can have a direct economic impact on industrial consumers. Besides the obvious financial impacts on both utilities and industrial customers, there are numerous indirect and intangible costs involved with power quality problems. The major reasons for this increased concern are newer generation load equipment, with power semiconductor devices and microcontrollers. Also the usage of adjustable speed motor drives and power factor correction equipment resulted in increased power system harmonics which impacts the power quality of entire power system. The awareness of power quality issues is increased even in the end utility customers and are challenging in the improvement of quality of power they are utilizing. The power quality is actually the quality of the voltage as power is the rate of energy delivery and which is proportional to the product of voltage and current. The power supply system can only control the quality of the voltage. Any significant deviation in the voltage magnitude or frequency is a power quality problem. In this paper the variations in magnitude of voltage is considered as a power quality problem [14].

The short – duration voltage decrease (between0.1 and 0.9pu in the rms voltage at the power frequency for durations from 0.5 cycle to 1 min.) is considered as sag as shown in Fig. 1. Voltage dips or sags usually associated with system faults and also caused by energization of heavy loads or starting of large motors.
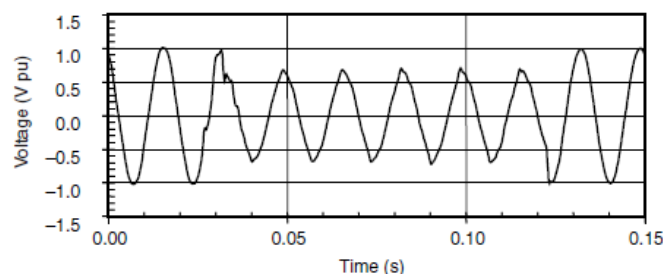


**Fig. 1:** Voltage Sag with decrease of 0.3pu for a duration of 0.08sec

A swell is defined as an increase of rms magnitude of voltage from 1.1 to 1.8 pu at power frequency for durations 0.5 cycle to 1 min, as shown in Fig. 2. Swells are usually associated with system fault conditions. The chance of getting voltage dips and interruptions originate in the transmission and distribution system is very high[12]. A voltage collapse occurs when the system try to serve much more load than the voltage can support [13]. Due to the use of the different types of sensitive electronic equipments, PQ issues have drawn substantial attention from both utilities and users [3].
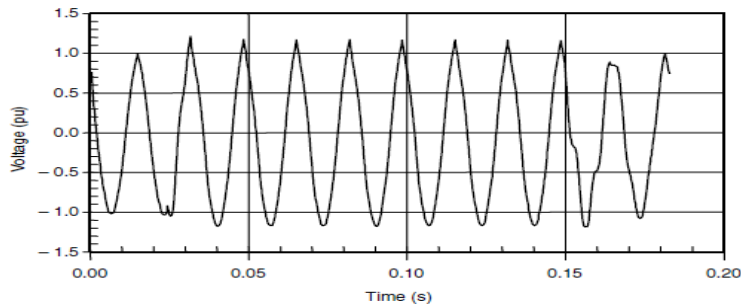
**Fig. 2:** Voltage Swell with increase of 0.2pu for a duration of 0.11sec

A distributed power flow controller (DPFC) is proposed in this paper to mitigate voltage sag and swell. The concept of DPFC is derived from the concept of eliminated dc link between shunt and series controllers of UPFC. The new technique is incorporating several small independent series converters as shown in Fig.3 [7].

A 4 bus IEEE standard system is considered for the work, to analyze the voltage sag and swell as shown in Fig. 4. The DPFC consists of one shunt and several series-connected converters. STATCOM is used as a shunt controller, while the numbers of SSSC are used as series converters [1]. In DPFC, there is a common connection between the AC terminals of the shunt and the series converters, which is the transmission line. Therefore, active power is exchanged through the AC terminals of the converters.
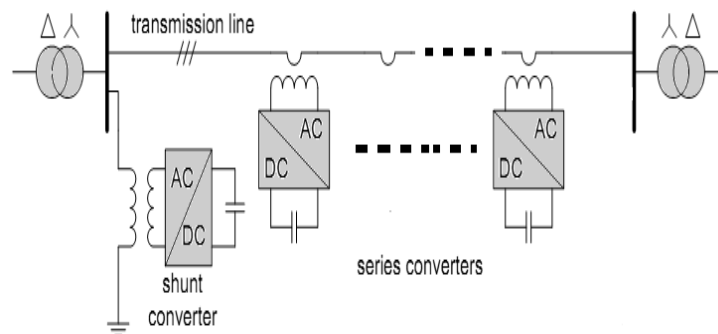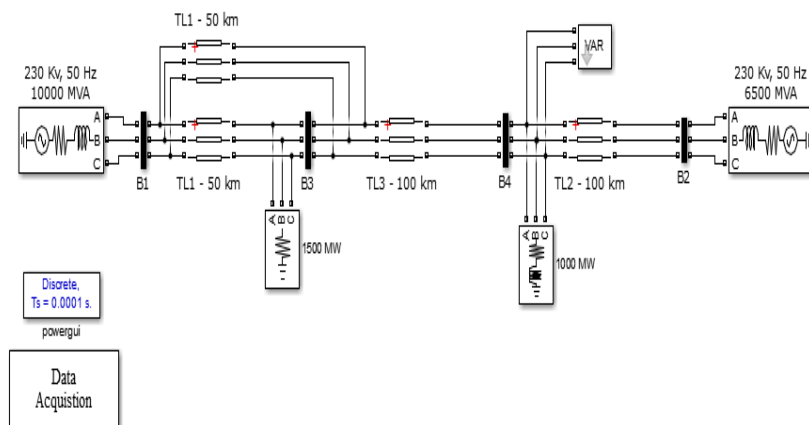


**Fig. 3:** The DPFC Structure



**Fig. 4:** IEEE Four Bus System

3 controlling logics are required for the operation of DPFC namely, central control, shunt control, and series control. The reference signals for both the shunt and series converters are generated by the central control unit of the DPFC, at fundamental frequency. Each series converter has its own series control. The controller is used to maintain the capacitor dc voltage of its own converter and to generate series voltage at the fundamental frequency that is prescribed by the central control. The shunt converter's fundamental frequency control aims to inject a controllable reactive current to grid and to keep the capacitor dc voltage at a constant level [1].

## II.     Conventional Control Of DPFC

A Conventional PI controlling technique is proposed for the improvement of the performance of the DPFC connected to the IEEE 4 bus system.
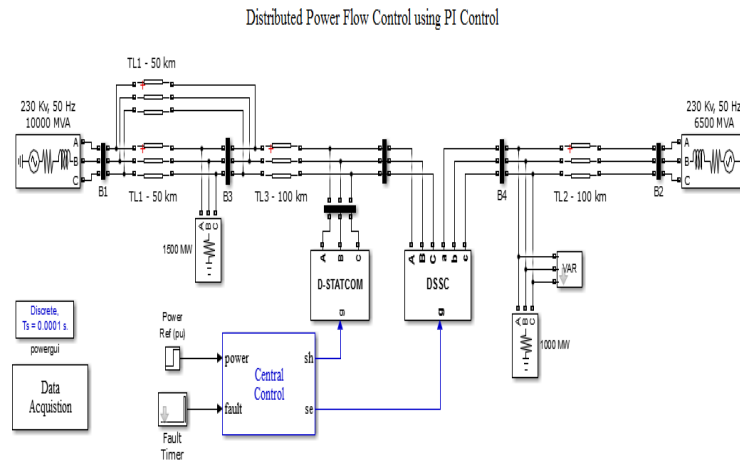


**Fig.5:** Distributed Power Flow Controller with PI Contol mechanisam

Observations are made for the variations in voltage of the bus at load with DPFC and without DPFC. It is found that without DPFC the voltage of the load bus is not reached to nominal value at any time of operation and is improved with DPFC.

## III.     DPFC With Fuzzy Control Mechanism

Modeling and control of dynamic systems belong to the fields in which fuzzy set techniques have received considerable attention, not only from the scientific community but also from industry. Many systems are not amenable to conventional modeling approaches due to the lack of precise, formal knowledge about the system, due to strongly nonlinear behavior, due to the high degree of uncertainty, or due to the time varying characteristics. To improve the efficiency of DPFC in the system an intelligent control strategy, namely fuzzy control mechanism is proposed for the power system engineer. The controlled strategy implemented by the engineers are prepared as set of rules that are simple to carry out manually but difficult to implement by using conventional control strategy[15].

In this proposed fuzzy controller approach the inputs are error (e) and change in error (Δe) generates required control signal. The design procedure of FLC consists of the following modules: 1) Fuzzification 2) Fuzzy Rule-base 3) Fuzzy Inference Engine (Decision Making Logic) and 4) Defuzzification. A Fuzzy controller operates by repeating a cycle of following four steps. First, measurements are taken of all variables that represent relevant conditions of the controlled process (Universal Discourse). Next, these measurements are converted into appropriate fuzzy sets to express measurement uncertainties (Fuzzification). Fuzzy models can be seen as logical models which use "if-then" rules to establish qualitative relationships among the variables in the model. Fuzzy sets serve as a smooth interface between the qualitative variables involved in the rules and the numerical data at the inputs and outputs of the model. The rule-based nature of fuzzy models allows the use of information expressed in the form of natural language statements and consequently makes the models transparent to interpretation and analysis. At the computational level, fuzzy models can be regarded as flexible mathematical structures that can approximate a large class of complex nonlinear systems to a desired degree of accuracy.  The fuzzified measurements are the used by the inference engine (Decision Making Logic) to evaluate the control rules stored in fuzzy rule base. The result of this evaluation is a output fuzzy set (or several fuzzy sets) defined on the universe of possible actions and the degree of membership of the output fuzzy set can be calculated by using Root Sum Square Method. This fuzzy set is then converted, in the final step of the cycle, into a crisp (single) value that, in some sense, is the best representative of the fuzzy set (Defuzzification). The defuzzified value represents the actions taken by the fuzzy controller in individual control cycles. Now, in the following Sections we develop the various components of FLC to solve power quality problem. Fuzzy controller is developed to generate required control signal it receives the input signal from the system and processing the data in different stages and generate required output.
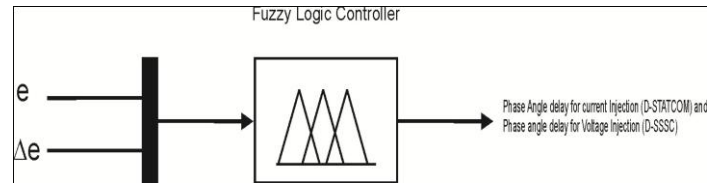
**Fig. 6:** Fuzzy Logic Controller

### 3.1 Selection of inputs and outputs:

In the design of fuzzy controller to address power quality problem the input variables selected as error (e) and change in error (Δe). It takes fuzzy input from fuzzifier in form of membership value matrix and uses fuzzy rule base to decide the fuzzy value of output. The control signal which represents rule base in terms of membership function. The upper limit and the lower limit of the error, change in error is specified on the previous experience of power system engineer.

### 3.2 Fuzzification:

Fuzzification is a process of converting crisp value of input data into suitable linguistic values through membership function. A general form of linguistic fuzzy if-then rules is:

$R_i$: If x is $A_i$ then y is $B_i$, i=1,2, ... ,K,

where x is the antecedent variable, which represents the input to the fuzzy system and y is the consequent variable representing the output of the fuzzy system. K denotes the number of rules.

### 3.3 Development of fuzzy decision rules

The construction of rule base involves:

- Based on the Expert Experience and Control Engineering Knowledge the rules are formed in the form of "if-then" and for the present two inputs –One output case, and for two number fuzzy input partitions, the maximum number 2×2=4 rules are to be formed.
- After forming all the rules they will be tabulated in the Decision Table.

Fuzzy decision rules developed based on previous experience of power system engineer a set of control rules can be developed these set of rules are vary person to person depends on personal experience in any particular field. There are two fuzzy variables for each input variable, therefore 4 decision rules are possible. This decision table consisting of linguistic numeric consequents of the rules. The number of rules depends on number of input variables, here we considered input variables are two so maximum of 4 rules can be possible. For example

1. If "error" is negative and "change in error" is negative than output is negative.
2. If "error" is negative and "change in error" is positive then "output" is zero.
3. If "error" is positive and "change in error" is negative then "output" is zero.
4. If "error" is positive and "change in "error" is positive then "output" is positive.

3.4 Fuzzy inference system

Fuzzy inference is the process of mapping from a given input to output using fuzzy logic. There are two fuzzy inference systems for implementation of fuzzy logic one is mamdani type and sugeno type these two types of inference system differs somewhat in the way output are determined.

### 3.5 Aggregation of fuzzy rule:

The fuzzy rule based system may contain more than one rule. the process of formulating overall conclusions from the individually specified consequents contributed by each rule is known as aggregation of the rule(or) computation of IF part of the rule is called aggregation.

### 3.6 Aggregation:

To represent in logical convenience new logical operators AND, OR, NOT are widely used in most of today's fuzzy logic applications

$$\text{AND: } \mu_{A \wedge B} = \min\{\mu_A, \mu_B\};$$
$$\text{OR: } \mu_{A \cup B} = \max\{\mu_A, \mu_B\};$$
$$\text{NOT: } \mu_{-A} = 1 - \mu_A$$

The degree which action is valid is given by the satisfactory of rules. This satisfactory is calculated by aggregation as degree of IF part.

### 3.7 Decision table
 The above 4 rules become the entries of decision table and are shown in shown in below.



N - Negative , P - Positive , Z – Zero
**Fig.7:** Decision Table

### 3.8 Composition
Calculation of THEN part of the rules is called composition.

### 3.9 Defuzzification
        If a crisp (numerical) output value is required, the output fuzzy set must be defuzzified. Defuzzification is a transformation that replaces a fuzzy set by a single numerical value representative of that set.

### 3.10 Algorithm For Design Of FLC
The following algorithm is proposed for designing of Fuzzy logic controller to mitigate power quality problem of four bus system.

**Step 1:** Select the input variables to enhance power quality issues like swell, sag. Error and change in error are selected as fuzzy inputs and the output of the FLC is proposed as the phase angle of injected current(D-STATCOM) and phase angle of injected voltage(D-SSSC).

**Step 2:** Selected input and out variables are then partitioned in to 2 regions and their membership functions have been defined.

**Step 3:** With the knowledge of the power quality issue like voltage swell and voltage sag (through the method, "Expert Experience and Control Engineering Knowledge"), 4 rules are framed to decide the membership function value of the output variable. The rules are then tabulated in the Decision-Table.

**Step 4:** Fuzzy output sets are formed and the strengths of each of the output membership function is estimated by Root Mean Square method.

**Step 5:** By applying Defuzzification, Crisp output is obtained.

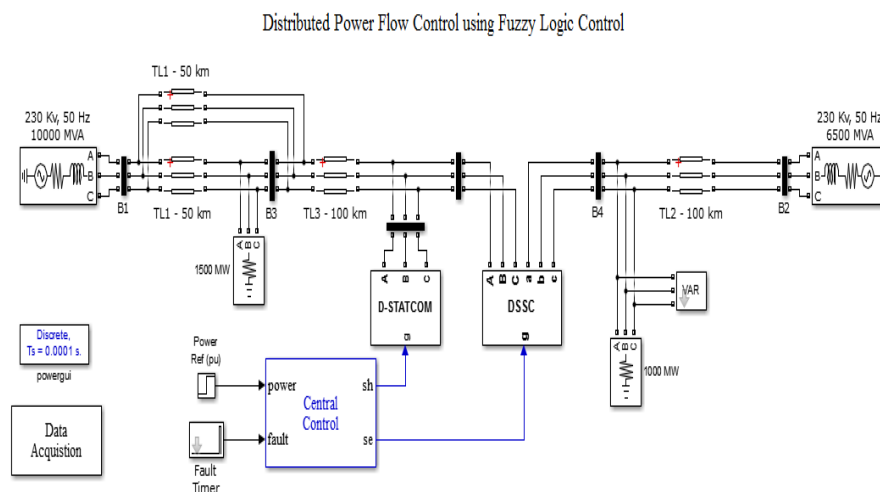**Step 6:** With the crisp value, output signal is generated.



**Fig.8:** Distributed Power Flow Controller with FUZZY Contol

# IV. Simulation Results

In this work a DPFC with fuzzy control mechanism have been proposed to enhance power quality (voltage swell, voltage sag) of four bus transmission system. Simulations are performed using MATLAB SIMULINK.The performance of proposed DPFC with fuzzy logic control mechanism is compared to DPFC with PI control mechanism.
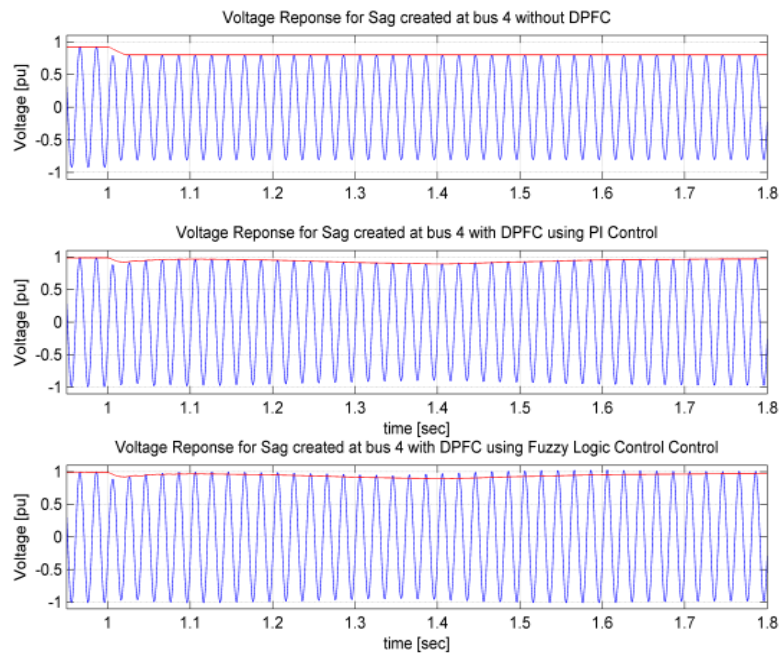


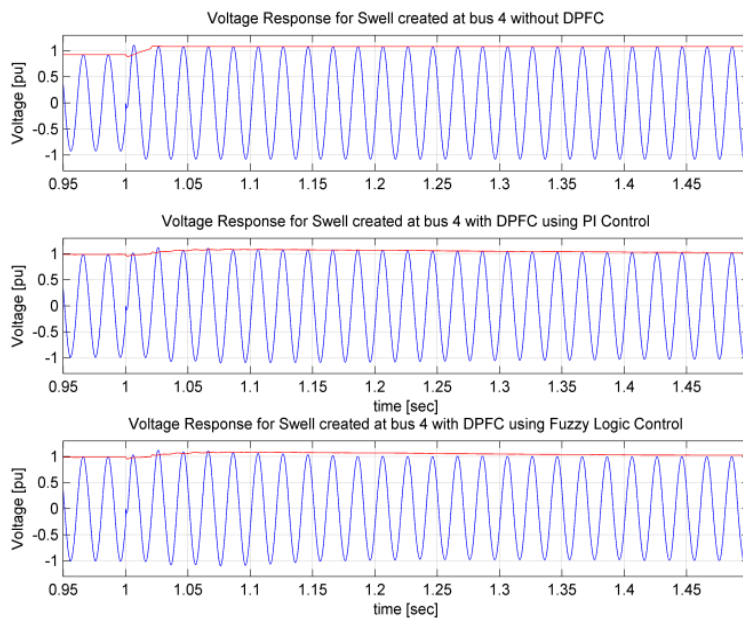**Fig.9:** Comparison of  PI Contol and Fuzzy logic for sag



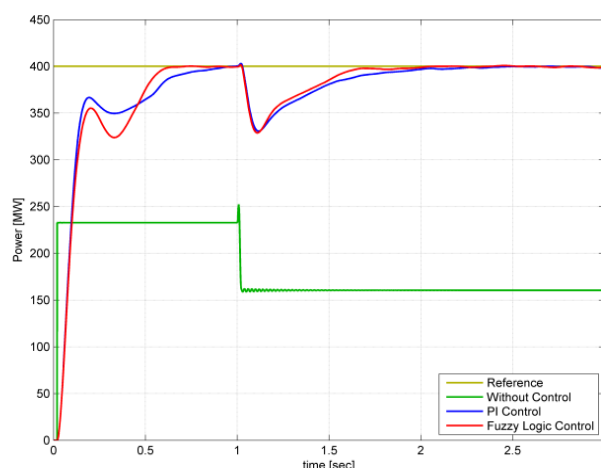**Fig.10:** Comparison of  PI Contol and Fuzzy logic for swell

**Fig.11:** Active power flow at bus-4 without DPFC and with DPFC

## V. Conclusion

In this paper for enhancement of power quality of transmission system a fuzzy control based DPFC is introduced at load bus of 4-bus system. The performance of proposed method is compared with PI based DPFC. Simulation results reveal that the proposed novel intelligent control methodology tackle power quality issues such as voltage sag, voltage swell and reactive power at load bus considerable compared to PI based DPFC.

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