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Design and Simulation of DSTATCOM using Fuzzy Logic Controller

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Abstract - *This project mainly focuses on the DSTATCOM and different control methodology of DC capacitor voltage basically PI controller is used to regulate dc capacitor voltage, by using different control algorithms i.e load compensation. However, when loading changes, the DC capacitor voltage effect on load compensation. In this topic, a fuzzy logic technique is applied to improve the DC link transient performance. The fuzzy logic-based supervisor varies the proportional and integral gains of the PI controller during the transient period straightaway after a load change. A significant drop in the error in dc-link capacitor voltage during load change compared to a normal PI controller is obtained. The proposed algorithm is proved by MATLAB Simulation.*

***Key Words*: Power Quality, Fuzzy logic, Harmonics, Flicker, DATACOM**

1. INTRODUCTION

The "Power Quality" is generally a broad theory and related to electrical distribution as well as utilization schemes that result from any voltage, frequency, a current abnormality from normal operation. For ideal electrical supply systems, power supplied accurate current and voltage are sinusoidal waveforms, being reliable and safe. But the electric utilities control voltage quality and levels but not able to control the current since load profile dominates the shape of current waveforms. Thus, the utility end must maintain the bus voltage quality at always. This consideration leads to power quality (PQ) is equal to voltage quality.

Defining accurately the Power Quality is a task; the common definitions are:

Definition: "Power quality is a summarizing concept, including different criteria to judge the technical quality of an electric power delivery". Another description is introduced and accepted by Ontario Hydro.

Definition: "Power Quality is the degree to which both the utilization and delivery of electric power affects the performance of electric equipment".

Definition: "Power quality problem is any power problem manifested in voltage, current, or frequency deviation that results in failure or misoperation of customer equipment".

Delivering a definite level of voltage stability and sinusoidal quality must worry for designers of the utility grid. When electrical utilization/ distribution end is unified, electric loads as well its profile, design of grid, utility maintenance with the nonlinearity of electric load degree factors disturbs power quality. Power Quality (PQ) has caused huge anxiety to utilities with rising use of sensitive as a well susceptible electronic as well computing device (e.g. desktop computer, uninterruptible power supplies, computer-aided design workstation, printers, fax, etc) different nonlinear loads.

2. The factors behind the increasing concern about the quality of power are:

- With the introduction of modern microelectronics and sensitive computer devices, the characteristics of electrical loads have changed significantly.
- Harmonics induces devices to cause failure and also reduce the efficiency of electrical distribution and network performance..

The electrical power system is currently interlinked, automated and thus any system failure will major financial consequences due to process shutdown, especially for large industrial customers. The sudden changes in electric load profile from initially linear sort of critically nonlinear, it creates continuous power quality problems always complicated to identify as well as complex.

Power Quality issues

- Harmonics (super, integral and interharmonics)
- Voltage fluctuations, swells, flicker, sags and Transients
- Voltage imbalance, voltage frequency and magnitude.

In the power system, here types of power quality instabilities. They are differentiated into types and their explanation important to categorize results for measurements as well as define electromagnetic phenomena, which results in power quality aspect. Instabilities derived from the supply side, as well as others by load itself.

- Short duration variations in voltage
- Long duration variations in voltage

- Transient conditions
- Voltage uncertainty
- Distortion of waveform

2. DSTATCOM

There are many changes in recent development in the usage of critical loads in all sectors, such as voltage sags, transient, swells and unbalance. This kind of disruptions that have triggered or shut down malfunctions and appear to lose sales. There are many strategies available to avoid malfunctioning of the devices due to voltage swells, sags. The usage of DSTATCOM to reduce voltage swell as well voltage sag is one of the broadly utilized approaches. Shunt controller, known as Distribution static compensators or DSTATCOM.DSTATCOM is an efficient tool in the distribution network to minimise disruptions due to power quality issues. Voltage swells are one of the critical disruptions in electricity systems. As seen the new DSTATCOM consisting of a voltage source inverter (VSI), a shunt inject transformer, a filtering unit and storage for energy unit that can be attached to the dc-link. Sags/swells of voltage can appear more generally than other phenomena of power quality. The most serious power quality challenges in the method of power delivery are these sags/swells. In the following segment. In an attempt to optimise certain devices for voltage sag, swell reduction as well as reactive power compensation in a network, the segment is intended to analyse and suggest the design of DSTATCOM.

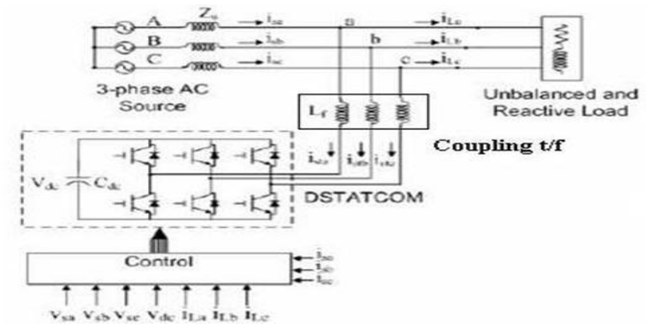

FIG-1: DSTATCOM basic model

2.1 DSTATCOM OPERATING PRINCIPLE

DSTATCOM is regulated reactive source that contains a shunt-connected Voltage Source Converter (VSC) and a DC connection capacitor that can produce or absorb reactive power. That similar to perfect synchronous system that produces a stable series of three simple frequency sinusoidal voltage with manageable amplitude and angle of phase. This ideal device has no inertia, has an immediate replay may not adjust the impedances of the device, and can produce reactive (together capacitive /inductive reactive power) internally. No reactive power is supplied to the device if t output voltage of VSC is equivalent to AC terminal voltage. If the output voltage is higher AC terminal voltage, the operating mode of DSTATCOM is capacitive / vice versa. In two voltages, the amount of reactive power flows will equal to variation.

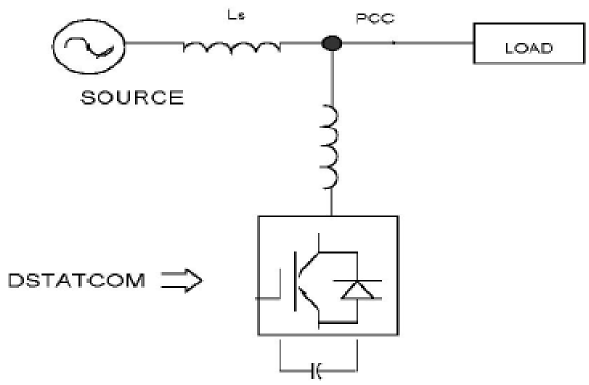

FIG.2: Basic structure of DSTATCOM in transmission line

It should be remembered that voltage control at Point of common coupling (PCC) as well modification of power factor are being accomplished at the same time. The compensation DSTATCOM applied for voltage control at PCC must be such that supply current contributes to supply voltages and supply current must in phase with supply voltages for power factor improvement. To studies of performances of DSTATCOM for reactive power compensation as well as power factor improvement, control algorithms described in this document are used.

3. CONTROLLING STRATEGY

This portion generally presents the DSTATCOM control method for DC capacitor voltage, usually, dc capacitor voltage controlled by the PI controller. Several control algorithm managed for load compensation. However, there is significant variance in dc capacitor voltage through load adjustments may influence compensation. The task for fuzzy supervision method based on logic is developed to increase dc link's transient performances. Through transient cycle straightaway after load variation, fuzzy logic dependent supervisor differs PI controller's proportional and integral gains. Compared to a common PI controller, a significant reduction in defect dc connection capacitor voltage all through load variation is achieved. Using comprehensive simulation tests, the effectiveness of the suggested approach is shown.

3.1 DSTATCOM FOR REGULATION OF VOLTAGE

At consumer stages, DSTATCOM increases voltage swell, sag in this method of the voltage controller (also named the decouple method) is used as a DSTATCOM control method. The dq0 revolving reference frame was used in this control scheme since it provides greater precision than stationary frame-based strategies. Three-phase voltage terminal are in Vabc, Iabc 3 -phase currents pumped into the system by DSTATCOM, Vrms is RMS at voltage terminal, Vdc is DC voltage determined in the capacitor, as well reference values are shown by superscripts. A phase-locked loop (PLL) is used in such a controller to synchronise 3phase voltage at converter output with zero crossings of the basic portion of phase-A terminal voltage. The angle f of the abc- dq0 (and dq0-abc) transition is then given by the PLL. For proportional-integral (PI) regulators still exist. First one is answerable to regulating the terminal voltages with ac network via the reactive power exchange. The reactive current reference Iq* is given by this PI regulator, which confined between pulse 1pu capacitive and minus 1pu inductive. Another PI regulator was responsible for maintaining dc voltage stable with the ac network by a limited active power transfer, reimbursing transformer as well inverter for active power losses. The active current reference Id* is offered by this PI regulator. After a dq0-to-abc transition, other two PI regulator evaluate voltage reference Vd* and Vq* send to converter's PWM signal generator. Finally, the 3-phase voltage needed at converters output Vab*.

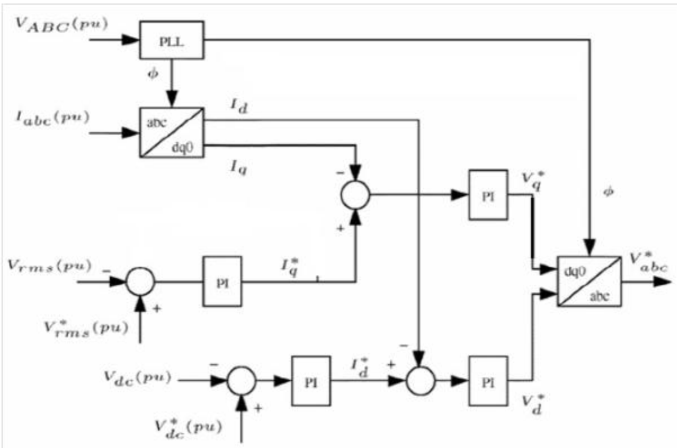

FIG-3: PROPOSED CONTROL TECHNIQUE OF DSTATCOM

3.2 DC -LINK PI CONTROLLER AND FUZZY CONTROLLER

It is assumed that the source voltages are controlled and rigid.

$$i^*_{fa} = i_{la} - i_{sa} = i_{la} - \frac{V_{sa} - \gamma(V_{sb} - V_{sc})}{\Delta}(P_{lavg} + P_{loss})$$

$$i^*_{fb} = i_{lb} - i_{ba} = i_{la} - \frac{V_{sb} - \gamma(V_{sc} - V_{sa})}{\Delta}(P_{lavg} + P_{loss}) \qquad (1)$$

$$i^*_{fc} = i_{lc} - i_{bc} = i_{lc} - \frac{V_{sc} + \gamma(V_{sa} - V_{sb})}{\Delta}(P_{lavg} + P_{loss})$$

where $\Delta = \sum_{j=a,b,c} V_{sj}^2$ and $\gamma = \tan\phi / \sqrt{3}$

For maintaining unity power factor initially being source equal to zero and hence equal zero. The word Pl avg is the mean load power rate and if there is no load adjustment, will be a fixed value. This is measured using the half-cycle moving average filter. Ploss is the amount of power must be taken from the source in an attempt to correct for the blackouts in the inverter. If this concept is not used, then the dc capacitor can supply these errors and the dc-link voltage will decrease. However, the specific losses that exist in the inverter are highly difficult to compute a PI controller, Ploss is thus obtained. The value of Ploss is differing at every half period cycle or regular interval 1800 at steady state. The sum of the term for P loss and Pl avg defines quantity power obtained from the source. It takes half a cycle for the moving average filter used to calculate Pl avg to resolve down to new average power valuation. The power for the load is momentarily delivered from DSTATCOM at period. If the load is increased, this tends to the down value of dc-link voltage of enhances appeared capacitor voltage unless the load is decreased. The capacitor voltage must stay as near to the reference value as possible for good compensation. Afterwards load change occurred, capacitor voltage takes 8 cycles to resolve, based on the Kp and Ki values. Profits are selected by trial and error most of the time. For the DSTATCOM programme, a method is given to obtain good Kp and Ki value. This was used during stable action as the basic values. Although likely to boost the quality of dc link through transient activity by modifying the PI controller's gains applied a set of the heuristic rule on skilled information. Also, technological advances such quicker DSPs allows us to rise the testing rate for a better input on how device answers to updates. Fuzzy based controller shown to function with nonlinear systems, such as DSTATCOM. It was shown in this article that fuzzy logic-based monitoring of gain of the dc-link PI controller enhances transient as well settling voltage regulation output of dc link. The applied fuzzy logic is programmed as acceptable. In the usual sequence, this article has been decided. A description of VSI configuration for DSTATCOM is mostly provided first and state-space analysis applied to simulate DSTATCOM operation is clarified. For this method, the fuzzy supervisor's model is explained. In the final section, the methods and results of the simulation are shown, showing increased performance of dc connections. There few active power-sharing among DSTATCOM and load throughout load changes. That refers to dc capacitor voltage being decreased or increased. The word Ploss is regulated using the PI controller to indicate that the voltage of the dc capacitor will not differ from the standard control output of the PI controller.

$$P_{loss} = K_p(v_{dc}^{ref} - v_{dc}) + K_i\left(\int (v_{dc}^{ref} - v_{dc})dt\right) \qquad (2)$$

The inaccuracy in dc-link voltage is input to the PI controller and output is the Ploss value. The value of Ploss is dependent on the Kp, Ki value and dc-link voltage error. Thus it important to properly tune Kp as well Ki. Due to the system's inherent non-linearity and difficult, it is impossible to tune the controller's gains. Usually, it was worked through experimentation. Using the energy theory proposed in, the basic values of Kp and Ki were designed. It has also been seen in the literary works that fuzzy monitoring in nonlinear systems could even boost performances of PID controller. However, most focus on setpoint alteration in control executions. The term derivative control not operated so when was using only with proportional control, enhancement instability may but may not be achieved that if operated with integral control and tuning for better performance is impossible.

3.3 DESIGN FOR THE SUPERVISOR FUZZY LOGIC FOR PI CONTROLLER

For a wide variety of control procedures, the PID controller is commonly utilized in the industry and provides adequate output until calibrated when the parameters are well established and there is not much variance. Because operational conditions differ, more adjustment for good performance might be required. Since many methods are dynamic and nonlinear, a good alternative appears to be fuzzy control. The literature demonstrates many methods where a fuzzy controller has removed the PI controller. However, it is necessary to use a conduct a detailed regulation instead of fully changing the control operation by tracking the gains by fuzzy technique to boost device ability. A PI controller chosen to manage the voltage of the dc connection as the inclusion of an integral term confirms zero steadies for state error. A disturbance used in dc connection capacitor voltage waveform since instantaneous symmetrical portion principle worked the compensator often supplies the oscillating portion of active control. The mean fluctuating power exchange in among the compensator As well load is therefore often zero. In the simulation performance, this disturbance can be seen in. The levelling of the fuzzy controller has configured to present a better output during the transient phase, regardless of the ripple involvement. Choosing the proper inputs and outputs and constructing each of four elements of fuzzy controller logic are some of the key facets of fuzzy design controller. In the paragraphs below, both of these will be mentioned: fuzzy controller also triggered during at transient condition and until the value of the dc connection voltage stabilises, gains of the controller are constant at a value of the stable state. A detailed explanation was already given for configuration of the fuzzy logic regulator.

$$\mathrm{err}(i) = V_{dc}^{ref} - V_{dc}(i) \quad (3)$$

$$\mathrm{derr}(i) = \mathrm{err}(i) - \mathrm{err}(i-1) \quad (4)$$

$$K_P = K_{pref} + \Delta K_p \quad (5)$$

$$K_i = K_{iref} + \Delta K_i \quad (6)$$

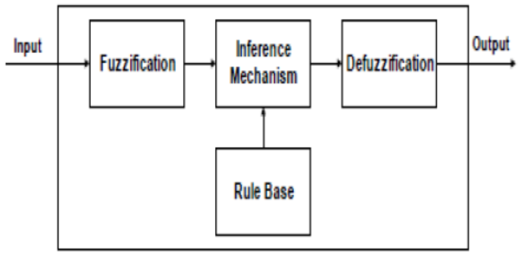

Fig 3.3 FUZZY CONTROLLER ARCHITECTURE

3.4 DEFFUZIFICATION

The interface for fuzzification alters the inputs to a shape in which the control algorithm can use them. It carries in crisp data input and allocates the membership function in a range of input signal drops to a membership value. Trapezoidal, exponential or triangular are standard input membership features. Seven triangular membership functions were chosen: NL (Negative Large), NS (Negative Small),NM (Negative Medium), Z (Zero), PM (Positive Medium),PS (Positive Small) and PL (Positive Large) for both errors (err) and error change (derr) the input membership functions. Based on the requirements of the method, the adjustment of the input membership function is carried out. A membership value relating to [0 1] applies to each membership function. It can be noted that either one or two membership functions will be effective for each error value or change in error.
The major functions for inference mechanism are a) the rules applicable to the present situation are decided based on the active membership in error functions and alter in error input. (b) As once rules are laid down, the assurance of the control action is determined on the membership values. This is known as the quantitative analysis of the premise. Thus, we will have a set of rules at end of this method, each with the specific assurance of being appropriate. In rule base through which control action is gained, the database carrying these rules is available. The next part the rule base addressed.

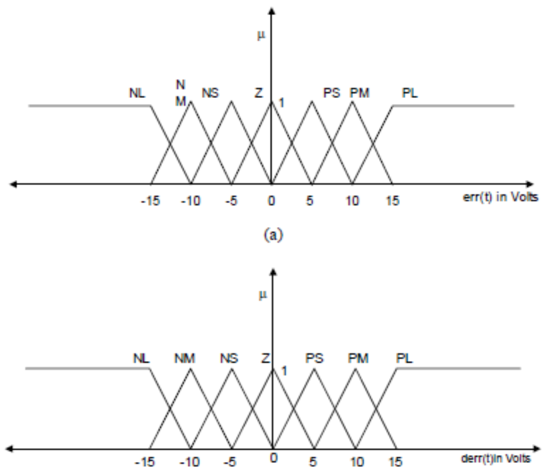

FIG 3.4 (a Functions for Membership for error inputs. (b) Membership functionality for error input shift in error inputs

This is regarded as the estimation of the premise. Thus, we will have a set of rules after such a process, each with a definite guarantee of being true. In the rule base through which control action is taken, the database holding these rules is available. In the next chapter, the rule base would be addressed. An instance of a rule is given. . (7). "change in error" is PM (positive medium) and If "error" is PL (positive large) "THEN "_Kp" is L (Large Kp) "_Ki" is SKi (Small Ki) The lowest operation used to evaluate guarantee called μpremise of law established by addition. The words PL and PM are the membership functions for inaccuracy and for alteration in inaccuracy respectively.

3.5 THE RULE BASED

A crucial factor in building the model is designing the rule base. How the rule base has been built is crucial to consider.. After a rise in the load without the implied ripple due to adjustment, displays a standard dc connection voltage waveform. Based upon the sign of error as well as the change of error, the waveform was separated into separate parts. Dependent on the part in the graph the waveform is in the rules in rule base are configured. The main points related in the design of rule. The following are significant points related in construction of rule base: a) If the error will high and error shift indicates a waveform of dc-link diverging through reference, Kp increases. B) If waveform exceeds reference value after to minimise overshoot and boost settling time, increase the Ki value. Two rule base matrice for Kp and Ki were created keeping these aspects in mind. Uh, the table gives the matrix base rule Kp and the table. The rule base matrix for Ki is given. LKi, SKi and Z are output membership features for proportional gain, and L, M, S and Z are the output membership features for the gain of integral. These matrices have laws, such as the example seen in, for all different pairs of error and error adjustment membership functions. Thus the rule and its surety are dictated by the rule base using data from the rule base. The mechanism for transforming the fuzzy outcome to a crisp control operation.

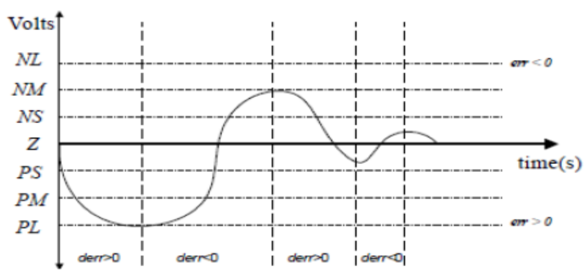

FIG 3.5 Typical dc-link voltage waveform after a load change

err v/s derr	NL	NM	NS	Z	PS	PM	PL
NL	L	L	L	M	S	S	Z
NM	L	L	M	S	S	Z	S
NS	L	M	S	S	Z	Z	Z
Z	M	Z	Z	Z	Z	Z	M
PS	Z	Z	Z	S	S	M	L
PM	S	Z	S	S	M	L	L
PL	Z	S	S	M	L	L	L

err v/s derr	NL	NM	NS	Z	PS	PM	PL
NL	SK_i	SK_i	SK_i	Z	Z	Z	Z
NM	SK_i	SK_i	SK_i	Z	Z	Z	Z
NS	LK_i	LK_i	LK_i	Z	Z	Z	Z
Z	LK_i	LK_i	LK_i	Z	LK_i	LK_i	LK_i
PS	Z	Z	Z	Z	LK_i	LK_i	LK_i
PM	Z	Z	Z	Z	SK_i	SK_i	SK_i
PL	Z	Z	Z	Z	SK_i	SK_i	SK_i

FIG-3.6 A. Rule base for change in kp **. B.** Rule base for change Ki

3.6. DEFUZZIFICATION

Inference mechanism gives us a list of norms with a μpremise each. These rules and about there various μpremise values are considered by the defuzzification mechanism, their impact is combined, and crisp, numerical outputs obtained. Thus the behaviour of the fuzzy controller is converted into a nonfuzzy controlled action. In this task, the' gravity of the centre' technique was working. If we're using the technique, the resulting crisp output is responsive to all the inference mechanism's effective fuzzy outputs. . The output membership features selected for Kp and Ki are shown below. The weighted element of centre value for active output membership values taken as the output according to this method, weights becoming area below the level line output. Upremise.

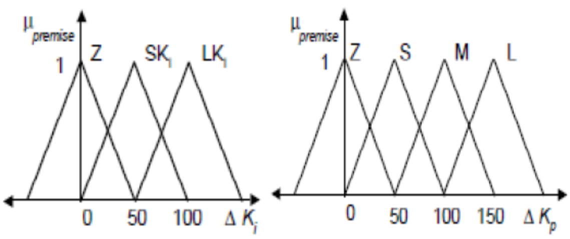

FIG 3.6 Output membership function

(a) For Kp (b) For Ki

4. Simulations and Result

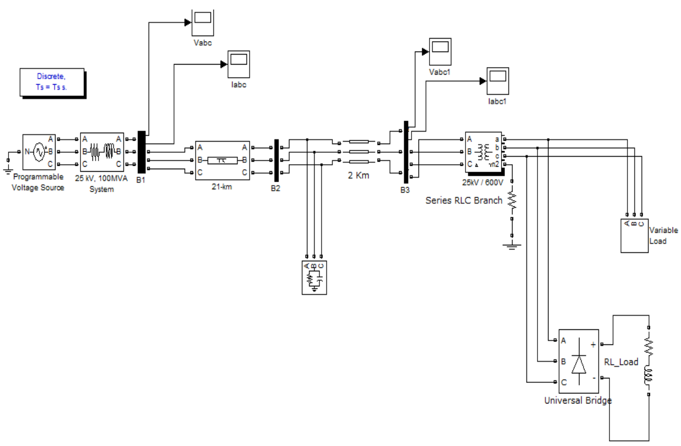

FIG-4.1: MATLAB Simulink model without DSTATCOM

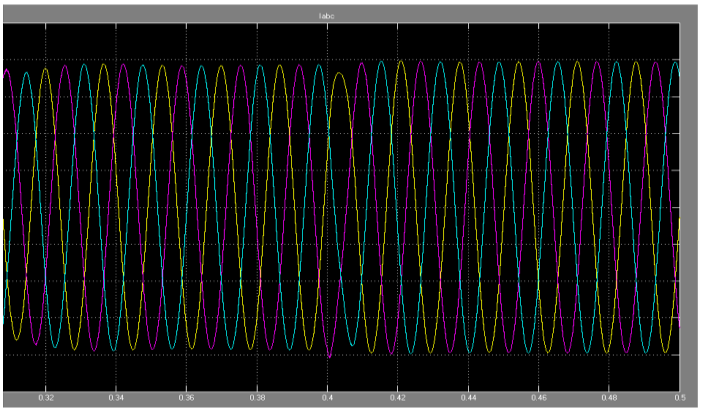

FIG-4.2 Current Waveforms

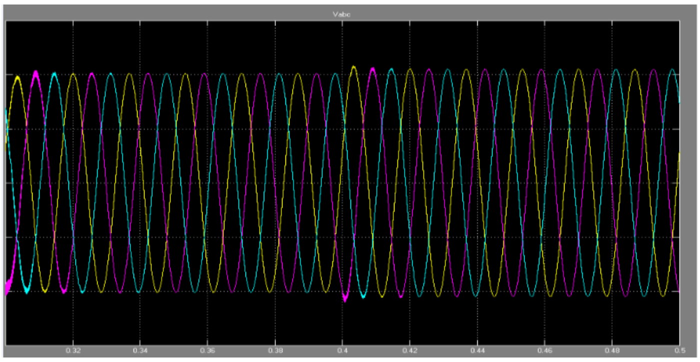

FIG-4.3: Voltage waveform.

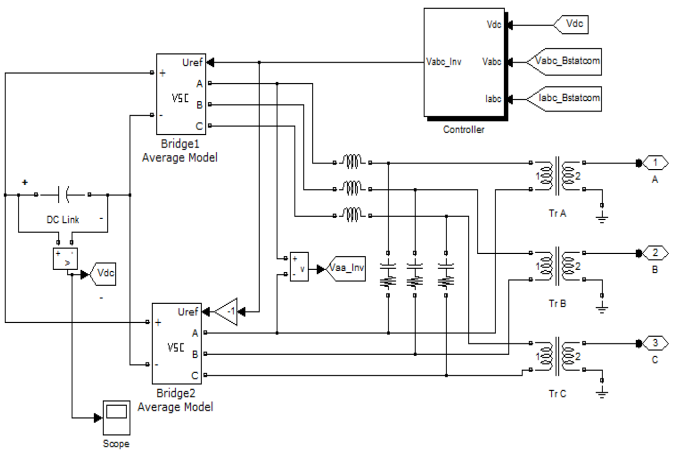

FIG-4.4: MATLAB Simulink model with DSTATCOM

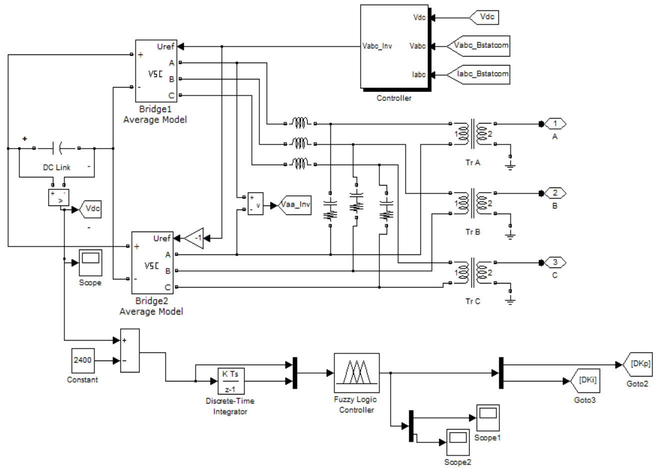

FIG-4.5: MATLAB Simulink model with fuzzy logic DSTATCOM

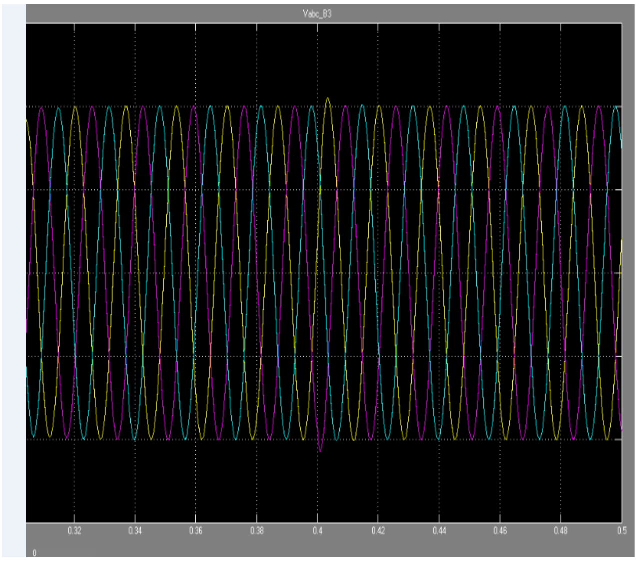

FIG-4.6: Output voltage introducing the fuzzy logic Dstatcom

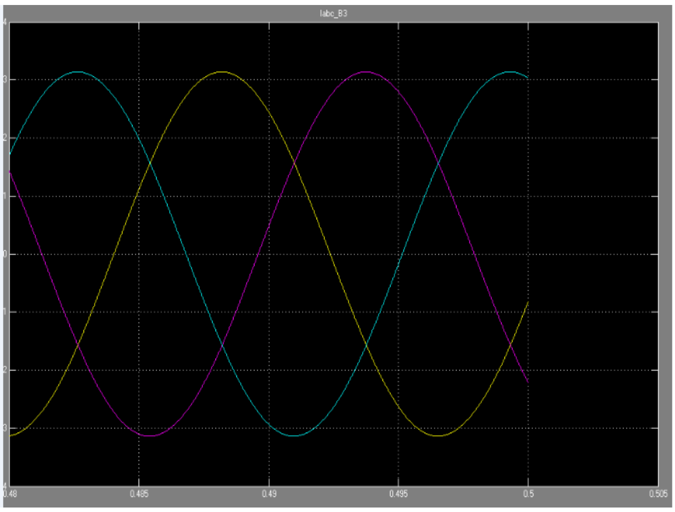

FIG-4.7: Output current introducing the fuzzy logic Dstatcom

5. CONCLUSION

The fuzzy supervisory logic control in a D-STATCOM was suggested to DC link PI controller. In a way that promotes quality, the supervisor changes the gain of the PI controller also through a transient phase. The MATLAB technological environment, the scheme was modelled and simulated using a case study. With and without the fuzzy boss, the output of DC connection voltage as well its performance compensation remained observed. The result of the simulations shows a 50-60% decrease on the voltage deviance of DC connection voltage with a fastest settling time. Better compensation was noted. Consequently, the execution of a fuzzy supervisor for DC link voltage control in D-STATCOM for load compensation has proved through simulations. For load compensation, the instantaneous symmetrical component hypothesis was used. Worthy compensation has perceived as source current THDs for each phase is 1.63%, 1.77% and 1.58% while load THDs are 12.37%, 10.5% and 14.54% consequential. Thus, simulation work for the implementation of a fuzzy supervisor for DC link voltage control in DSTATCOM by using the instantaneous symmetrical component concept for the load compensation has been performed.

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