AMSE JOURNALS –2014-Series: Modelling A; Vol. 87; N° 2; pp 1-18
Submitted May 2013; Revised Oct. 30, 2014; Accepted April 20, 2014

Fuzzy Based Simulation of D- STATCOM and DVR in Power Systems

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Abstract

A power quality problem is an occurrence manifested as a non- standard voltage, current or frequency that results is a failure or mis-operation of end user requirements. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruption which can cost significant financial losses. The present work is to identify the prominent concerns in this area and hence the measures that can entrance the quality of the power of recommended using soft computing method especially fuzzy control systems.

This work describes the application of fuzzy techniques of correcting the supply voltage sag, swell and interruption in a distributed system. At present a wide range of very flexible controllers, which catalyze on newly available power electronics components, are emerging for custom power applications. Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices, both of them based on the “Voltage Source converters” (VSC) principle. A “Dynamic Voltage Restorer” (DVR) injects a voltage in series with the system voltage and a “Distribution static compensator” (D-STATCOM) injects a current into the system to correct the voltage sag, swell and interruption. Comprehensive results are presented to assess the performance of each device as a potential custom power solution.

The aim of control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, winder system disturbances. The control system only measures the r.m.s. voltages at the load point. The PI controller process the error signal general the required angle to drive the error to zero. In this paper a PI-like FKBC (fuzzy knowledge based controller) is employed in place of conventional PI- controller.

Key words

D-STATCOM, DVR, VSC, PI-controller

1. Introduction

One of the most common power quality problems today is voltage dips. In a three-phase system a voltage dip is by nature a three phase phenomenon, which affects both the phase to phase and phase to ground voltages. Typical faults in power system are single phase or multiple-phase short circuits, which heads to high currents. The high current results in a voltage drop over the network impedance. At the fault location the voltage in the faulted phase drops close to zero, whereas in the non-faulted phases it remains more or less unchanged. Off course, for an industry an voltage is worse the a voltage dip, but voltage dip occur more offend and cause severe problems and economical losses. Utilities offend focus on disturbances from end-user equipment as the main power quality problems. Voltage dips mainly have their origin in the high here voltage levels. Faults due to lightening, is one of the most common causes to voltage dips on over head lines.

There are different ways to mitigate voltage dips swell and interruptions in the transmission and distribution systems. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Among these, the Distribution static compensator (D-STATCOM) and Dynamic Voltage Restorer (DVR) are most effective devices, both of them based on the Voltage Source Converts (VSC) principles. A new PWM- based control scheme has been implemented to control the electronic valves in the two- level VSC used in the D-STATCOM and DVR (S.V. Ravikumar & S. Siva Nagaraju 2007). The fuzzy PI- controller to process the error signal generates the required angle to drive the error to zero. A PI-like FKBC is designed to process the error signal to operate the PI-controller. The sections the DVR, D-STATCOM, PI- controller, PI-like FKBC subsequent and simulation Results have been organized.

2. Dynamic Voltage Restorer, (DVR)

The series voltage controller is connected in series with the protected load in Fig.1 Usually the connection is made via a transformer, but configurations with direct connection via power electronics also exist. The VSC converter generates the reactive power needed while the active power is taken from energy storage. Fig.2 shows the schematic diagram of a DVR, which is a circuit represents the The venin's equivalent circuit of DVR system.

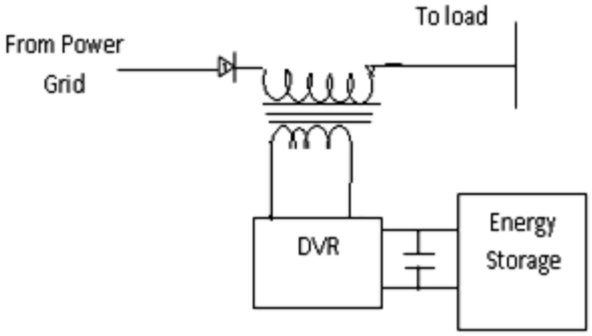

Fig.1 Standard Configuration of DVR

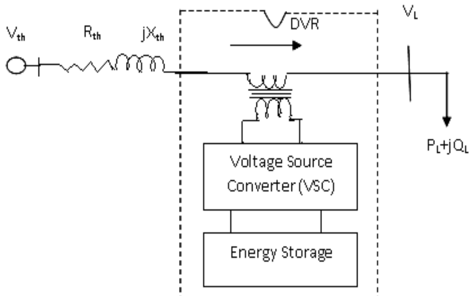

Fig.2 Schematic diagram of a DVR

The system impedance Z_{eh} depends on the fault level of the load bus. When the system voltage V_{th} drops, the DVR injects a series voltage V_{DVR} through the injection forms former so that desired load magnitude ½ can be maintained. The series injected voltage of the DVR can write as:

$$V_{DVR} = V_L + Z_{th} I_L - V_{th} \qquad (1)$$

Where V_L = Desired load voltage magnitude

Z_{th} = Load impedance (Thevenin's impedance)

$= R_{th} + jX_{th}$

I_L = Load Current

V_{th} = System voltage during fault condition

The load current is given by:

$$I_L = \frac{(P_L + ZQ_L)}{V_L} \qquad (2)$$

When V_L is considered as a reference.

Equation (1) can be written as:

$$V_{DVR} \angle \propto = V_L \angle 0 + Z_{th} I_L \angle(\beta - \theta) - V_{th} \angle \delta \qquad (3)$$

Here $\propto$, β and δ are the angle of V_{DVR} , Z_{th} and V_{th} respectively and 0 is load power factor angle. also $\theta = tan^{-1}(Q_L/P_L)$. The complex power injection of the DVR can be written as:

$$S_{DVR} = V_{DVR} \quad I_L^* \qquad (4)$$

It may be mentioned here that when the injected voltage V_{DVR} is kept in quadrature with I_L no active power injection by the DVR is required to correct the voltage. It requires the injection of only reactive power and the DVR itself is capable of generating the reactive power.

2.1 D-STAT COM (Shunt voltage controller)

It consists of a two level VSC, a dc energy storage device, a coupiling transformer connected in shunt to the distribution network through a coupiling transformer. The VSC converters convert's the dc voltage across the storage device into a set of three phase ac output voltages. Suitable adjustment of the phase and magnitude of the D-STAT COM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system, thus allowing the device to absorb or generate controllable active and reactive power.

In Fig.3 the shunt injected current I_{sh} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{th}. The value of I_{sh} can be controlled by adjusting the output voltage of the converter. The shunt injected I_{sh} can be written as (see Fig. 3)

$$I_{sh} = I_L - I_s = I_L - \frac{V_{th} - V_L}{Z_{th}} \quad (5)$$

D-STATCOM, which is schematically depicted in Fig. 3

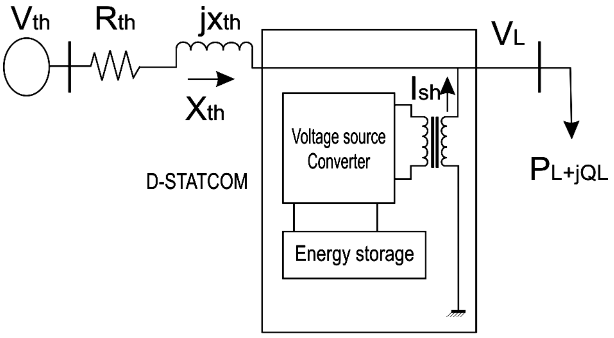

Fig.3 Schematic diagram of a D-STATCOM

$$I_{sh}\angle\eta = I_L\angle-\theta - \frac{V_{th}}{Z_{th}}\angle(\delta-\beta) + \frac{V_L}{Z_{th}}\angle-\beta \quad (6)$$

The complex power injection of D-STATCOM can be expressed as:

$$S_{sh} = V_L * I_{sh} \quad (7)$$

It may be mentioned that the effectiveness of the D-STATCOM in correcting voltage sag depends on the value of Z_{th} or fault level of the load bus. When the shunt injected current I_{sh} is kept in quadrature with V_L the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of I_{sh} is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system. The control scheme for the D-STATCOM follows the same principle as for DVR.

2.1.1 Test System for DVR and D-STATCOM

Single line diagram of the test system for DVR and D-STATCOM are shunt in Fig. 4 & Fig. 5 respectively. DVR test system is composed of 0.13 kv, 50 Hz generation system feeding two transmission lines through a three winding transformer connected in $\gamma/\Delta/\Delta, 13/115/15$ kv. such transmission lines feed two distribution networks through two transformers connected in $\gamma\gamma\gamma$, $230/11/11$ kv. A varying load is connected to the 11 kv, secondary side of transformer.

Tertiary winding is to provide instantaneous voltage support at the load point. A 750 μF capacitor on the dc side provides the D-STATCOM energy storage capabilities.

2.2 PI-Controller

The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. Such error is processed by a PI-Controller the output is the angle δ , which is provided to the PWM signal generator.

The PI-Controller process the error signal generates the required angle to drive the error to zero i.e. the load rms voltage is brought back to the reference voltage. Fig.6 shows indirect PI-Controller.

A two level D-STATCOM is connected in the 11kv.

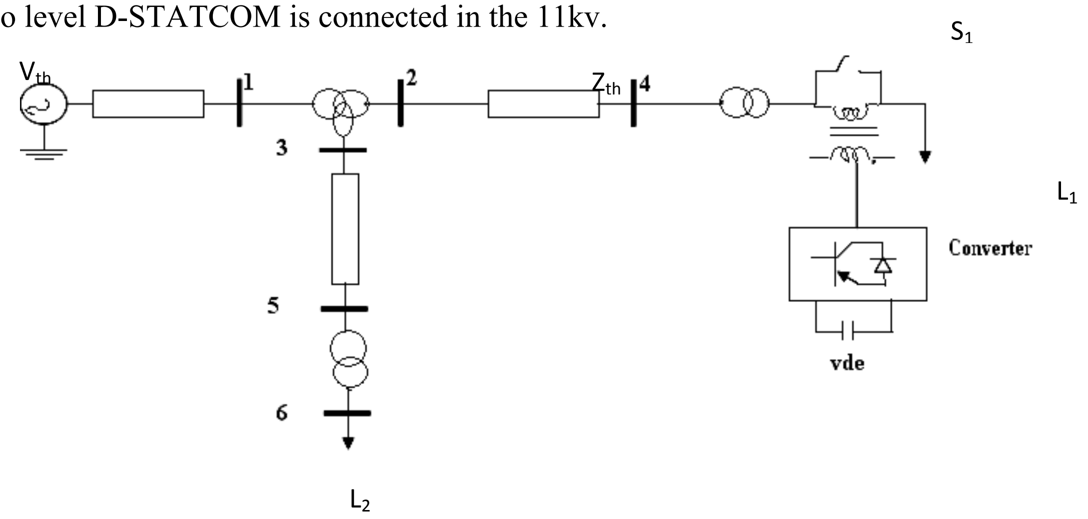

Fig.4 Single Line diagram of the test system for DVR

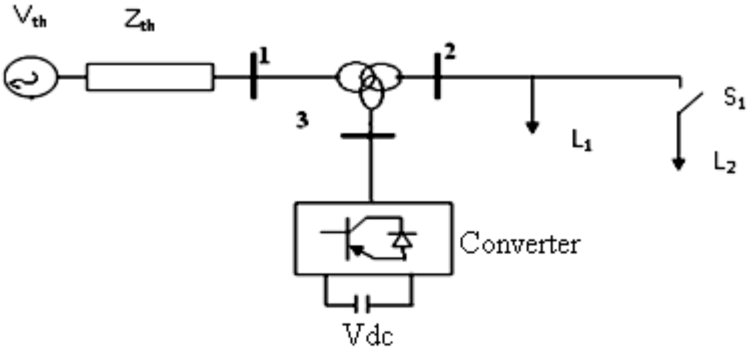

Fig. 5 Single Line diagram of the test system for D-Statcom

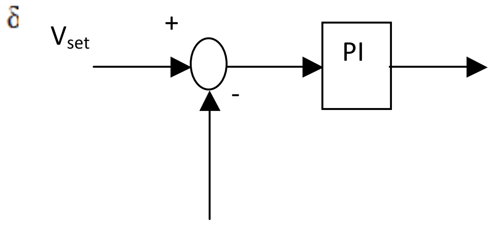

Fig.6 Indirect PI-Controller

The simulated signal V control is phase – modulated by means of the angle δ

$$V_A = \sin(wt + s)$$

$$V_B = \sin[(wt + s - 2\pi/3)]$$

$$V_C = \sin[(wt + s) + 2\pi/3] \quad (8)$$

The modulated signal V control is compared against a triangular signed V_T in order to generate the switching signals for the VSC valves. The main parameters of the sinusoidal PWM scheme are the amplitude modulation index of signal and the frequency modulation index of the triangulation signal.

2.3 PI-like FKBC

2.3.1 Knowledge Representation in FKBCs

A knowledge based controllers (KBC) can be identified as a highly specialized knowledge based systems (KBS) designed for performing a specific task during a particular phase of the lifecycle of a process control system. No design technique for closed loop control can proceed without some implicit or explicit knowledge about the process to be controlled. Knowledge here means a model which provides a conceptual structure to capture those aspects of the process which accurately represent its behavior. In our study use of a KBS replaces completely the conventional control element of a process control system and is known as a “Direct Expert control system (DECS)”. One particular instance of the class of DECS is the so- called “Fuzzy knowledge Based Controller (FKBC)” which employs a knowledge representation technique and inference engine based on fuzzy logic. DECSs constitutes a class of KBCs based on having the KBS in the closed loop, thus replacing completely the conventional control element i.e. PI-controller. One particulars subclass of DECSs are the FKBCs. The problem of regulatory control and the corresponding FKBC are considered here. The regulatory FKBC considered is built with the purpose of achieving the following three objectives:

To remove any significant error in process output y(k) by appropriate adjustment of the control output u(k) .

(i) To prevent process output from exceeding some user specified constraint Y_c i.e., for each k, Y(k) should be less or equal Y_c .

(ii) To produce smooth control action near the set- point, i.e. minor fluctuations in the process output are not passed further to the control output.

Although the above control objectives are typical of most industrial applications, a conventional PI-Controller cannot handle all three of them unless extended by some additional heurish logic. On the other hand, an experienced process operation can easily meet all above three control objectives. Thus the idea behind a FKBC is to build a KBS which employs the process operator’s experience in the form of IF-THEN production Rules.

2.3.2 Conventional PI-Controller

A Conventional PI- Controller uses analytical expression of the following form to compute the control action:

$$u = K_p . e + K_I . \int_t edt \quad (9)$$

When this expression is differentiated, one obtains:

$$u = K_p.e + K_I.e \tag{10}$$

The discrete time version of this equation is written as:

$$\Delta u(k) = K_p.\Delta e(k) + K_I.e(k) \tag{11}$$

Where $\Delta u(k)$ is the change if – control output, where $u(k)$ is the control output, and we have that:

$$\Delta u(k) = u(k) - u(k-1) \tag{12}$$

Also $\Delta e(k)$ is the error and we have that

$$e(k) = y_{sp} - y(k) \tag{13}$$

Where y(k) is the system output and

y_{sp} is the set point (desired system output)

And $\Delta e(k)$ is change error and we have that:

$$\Delta e(k) = e(k) - e(k-1) \tag{14}$$

Where k is k^{th} sampling time

The control objectives listed earlier would require variable gains near the set point i.e. small K_I near the y_{sp} and a very large K_I near constraint. Thus a simple P_I controller is inherently incapable of achieving all of the above control objectives and has to be implemented with the help of additional heuristic logic which is could allows the desired gain modification when required.

2.3.3 Development of Rule base of FKBC for PI- controller

The FKBC employs a knowledge base consisting of production rules of the form

If (Process state) THEN (Control output)

Instead of the analytical expression defining the conventional PI-Controller. The (process state) part of the rule is called the rule antecedent and contains a description of the process output at the K^{th} sampling instant. The description of this process output is done in terms of particular values of error, change of error, and the constraint.

The (Control output) part of the rule is called the rule consequent and contains a description of the control output which should be produced given the particular process output in the rule avitecedent. This description is in terms of the value of the change in- control output.

This FKBC is modeled at the same level of resolution as the conventional PI-Controller.

The analytical representation only states the relationship between certain variables, namely e, Δe and Δu, without providing any information at all as to the purpose which this relationship serves. Whereas, the three variables by explicitly stating the directionality of this relationship. i.e. from e and Δe to Δu.

The values which ‘e’ takes in a production rule are verbally expressed as negative big (NB), negative small (NS), Zero (Z0), Positive small (PS), positive big (PB) and constraint (c). A value such as PS expresses the knowledge that the current value of the process output y(k) is below the set point, since we have that e(k) = y_{sp}-y(k) and the difference between y_{sp} and y(k) is rather small. A value of error (e) such as NB expresses the fact that y(k) is above the set point and the difference between y_{sp} and y(k) is rather harge. The value for change – of- error (Δe) are negative big (NB), small (S) and positive big (PB). A value of PB expresses the knowledge that the current process output y(k) has significantly decreased its value compared to its previous value y(k-1), sing $\Delta e(k) = (y(k) - y(k-1))$. Similarly, when y(k) is NB this means that the current value of the process output is significantly bigger than its previous value, of $\Delta e(k)$ means that the values of y(k) and y(k-1) are close enough to each other and y(k) is either increasing or decreasing.

The value of the change – in – control $\Delta 4$ output are expressed as negative big (NB), negative small (NS), Zero (Z0), Positive small (PS), positive big (PB) and drastic change (DC). These values express the magnitude of the current incremental change in control output which should be added, in the case of positive values, or subtracted, in the case of negative values, to / from the value of the previous control output $4(k-1)$ i.e. $+u(k) - 4(k-1)$ or $u(k-1) - 4(k)$ or $\pm 4(k) \mp 4(k-1)$

No one can see that in the case of a FKBC the values of error (e) and change of error (Δe) express explicitly error is NS when the difference $y(k-1) - y(k)$ is big and$y(k) < y(k-1)$. In the case of convention PI- controller, an error value of 11.4 is just a real number and one cannot say much about its magnitude i.e. small, big etc. unless one pats it in the context of the whole range of the possible values of error (e). Neither can one say that 11.4 express the fact that $y_{sp} < y(k)$ since this relationship is not explicit in the analytic expression describing the controller.

The rule base of the FKBC is divided into two groups of rules:

1. First group which is always active i.e. incremental change in control output. These are the so- called active rules.
2. Second group which becomes active only when the process output is near or enters the constraint. These are the so- called constraint rules. The incremental change in control output determined from this group of rules is added/ substrate from the one already determined by the first group of rules.

   A rule from the first group has following for as:

   If value of $e(k)$ is (verbal value) AND value of $\Delta e(k)$ is (verbal value) THEN value of $\Delta u(k)$ is verbal value.

If value of $e(k)$ is PB AND value of $\Delta e(k)$ is PB THEN value of $\Delta u(k)$ is PS

Let us see now what such a rule actually means consider first the rule antecedent. The possible combination of positive/ negative values of $e(k)$ and $\Delta\, e(k)$ are as follows:

(Positive ‘e’, Positive ‘ Δ e’), (Positive ‘e’, Negative ‘ Δ e’),

(Negative ‘e’, Positive ‘ Δ e’), (Negative ‘e’, Negative‘ Δ e’),

The above four combinations are describes as below :

(a) The combination (Positive e(k), negative $\Delta\, e(k)$)) means that the current process output y(k) is below the set point since $e(k) = y_{sp} - y(k) > 0$ and increasing, since$\Delta\, e(k) = -y(k) - y(k-1) < 0$. Thus, the current process output is approaching the set point from below.

(b) The combination (negative $e(k)$, Positive $\Delta\, e(k)$) means that the current process output is above the set point and decreasing. Thus the process output is approaching the set-point from above. The combination (negative $e(k)$, negative $\Delta e(k)$) means that the current process output is above the set point and increasing. Thus the process output is moving further away from the set point and approaching over shoot.

(c) The combination (positive $e(k)$, positive $\Delta e(k)$) means that the current process output is below the set-point and decreasing. Thus the process output is moving further away from the set-point and approaching under shoot.

In this context, the rule antecedent from our example is of the type (positive $e(k)$, positive $\Delta\, e(k)$).The fact that both $e(k)$ and $\Delta\, e(k)$ are ‘large’ means that the current process output is below the set – point at a large distance from it and it has settled at this particular position after having made a large step in the direction of the set – point. Thus since the process output is moving in the direction of the set point with a large step, the rule consequent prescribes a small $\Delta 4(k)$ to be added to the previous of the set – point without going above it. The rest of the active rules are given in table 1.

Δe ⟶ Table 1. Rule base

e ↓

Δe e	SN	S	LP
LN	SN	LP	LN
SN	ZO	SN	SN
ZO	-	ZO	-
SP	SP	SP	ZO
LP	LP	LP	SP

Here SN= Small Negative, S= Small, LP= Large Positive

SP= Small Positive, LN= Large Negative, ZO= Zero, Δe = Change in error

In the table form of the rule base, the second row and first column, for example,

IF value of $e(k)$ is SN and value of $\Delta\ e(k)$ is NB

THEN value of $\Delta\ u(k)$ is Z0

2.3.4 Constraint Rules

These are three rules in the constraint rules which prescribe a control action when the error is in the constraint region, approaching it, or leaving it.

Constraint Rule 1

IF value of $e(k)$ is in constraint region THEN value of $\Delta\ u(k)$ is DC (Drastic change)

This rule specifies the magnified of the additional $\Delta\ u(k)$ to be added to the one already determined by the active rules when $e(k)$ is in the constraint region.

Constraint Rule 2

IF value of $e(k)$ enters constraint region THEN start summing up the value of $\Delta\ u(k)$ determined by constraint rule 1

Constraint Rule 3

IF value of $e(k)$ leaves constraint region THEN subtract the value of $\Delta\ u(k)$ determined by constraint rule 2

While the value of $e(k)$ is in the constraint region, the latter rule is necessary to prevent the drastic change (DC) in the value of the control output from dominating the value of the control output computed for the region outside of the constraint.

2. 4 Fuzzy Sets

The fuzzy sets for typical rules of PI-like FKBC are shown in Fig.7 in the domain (-6,6). These rules are:

IF e is LN and $\Delta\ e$ is Z0 THEN $\Delta\ u$ is LP

IF „ is SN and „ is Z0 THEN „ is PS

IF „ is Z0 and „ is LP THEN „ is SN LP

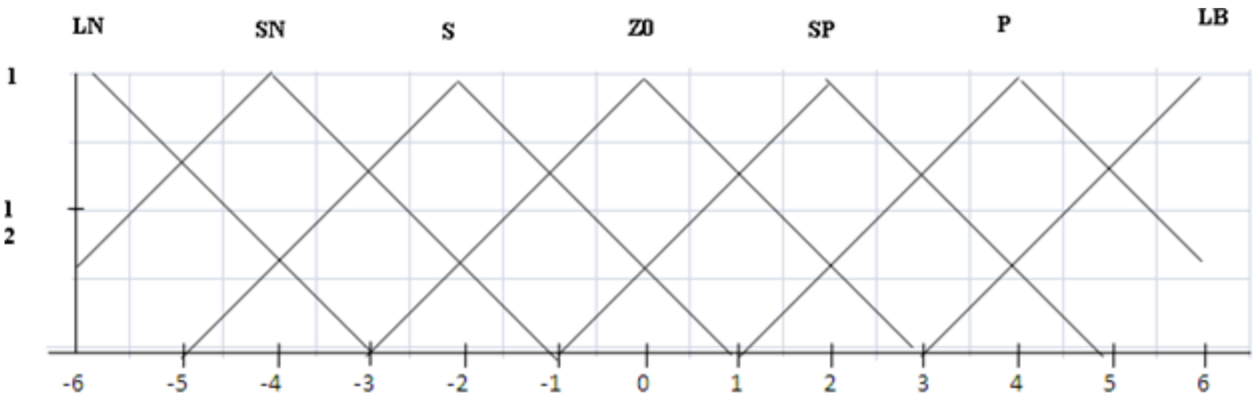

Fig. 7 The Fuzzy sets LN, SN, ZO, SP & LP on the domain (-6,6)

2.5 Fuzzification Procedure

There are two basic types of inferences i.e. compositions based inference and individual rule based inference. In composition based inference, the fuzzification procedure is defined in the case of PI-like FKBC as below:

Let the crisp input values of e and Δe be e^* and Δe^* . It is these two values that have to be fuzzified as defined in the form of membership function as given below:-

$$\mu_{e^*}\begin{cases} 1 \; if \; e=e^* and \; e \in \varepsilon \\ 0 \; otherwise \end{cases} \tag{15}$$

$$\mu_{\Delta e^*}\begin{cases} 1 \; if \; \Delta e=\Delta e^* and \; \Delta e \in \varepsilon \\ 0 \; otherwise \end{cases} \tag{16}$$

In the case of individual rule based inference the result of defuzzication is obtained as follows:

Let as consider the K-th rule of the PI-like FKBC.

IF e is SN and Δ e is SP THEN Δ u is Z0

Where the membership functions of linguistic variables SN, SP and Z0 are $\mu_{SN(K)}, \mu_{SP(K)}$ and $\mu_{Z0(K)}$, for the crisp values of e^* and $\Delta\, e^*$ the fuzzification are $\mu_{SN(e^*)}$ and $\mu_{SP(\Delta e^*)}$.

2.6 Defuzzification Procedure

Out of many defuzzification procedures, centre of Area defuzzification method is chosen.

The centre of Area method is the best well-known defuzzification method. In the discrete case $\{U = (u_1, \dots \dots . u_2)\}$ this results in:

$$u^* = \frac{\sum_{i=1}^{\ell} u_i \mu_u(ui)}{\sum_{i=1}^{\ell} \mu_u(ui)} \tag{17}$$

$$= \frac{\sum_{i=1}^{\ell} u_i . \overset{max}{k} \mu_{CLU(k)}(ui)}{\sum_{i=1}^{\ell} \overset{max}{k} \mu_{CLU(k)}(ui)} \qquad (18)$$

Where μ_{CLU}membership function of clipped fuzzy set (CLU) Fig.8 is shows the two clipped fuzzy sets for the purpose of defuzzification.

So this method determines the centre of the area below the combined membership function Fig. 8 shows this operation in a graphical way. It can be seen that this defuzzification method takes into account the area A U as a whole. Thus if the areas of two clipped fuzzy sets constituting U over lap (see Fig.8), then the over lapping area is not reflected in the above formula 18.

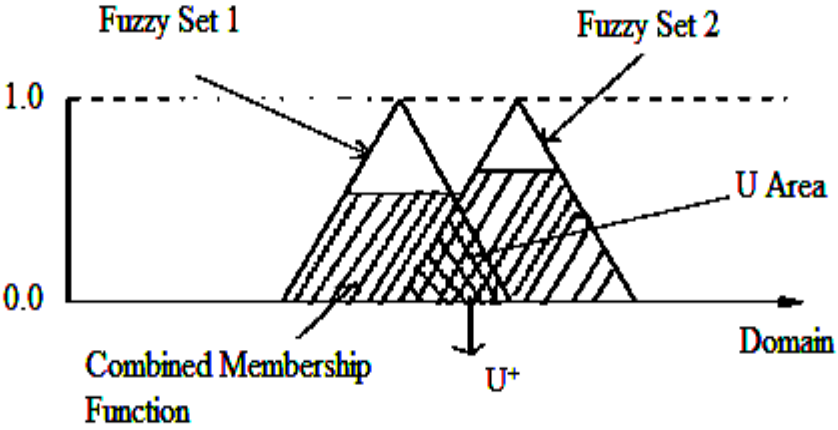

Fig.8 Two Clipped Fuzzy Sets for Centre- of- Area defuzzification

3. Simulation Results

3.1 Simulation Results of D-STATCOM

Case1: Simulation Results of voltage sag during single line to ground fault

The first simulation contains no. D-STATCOM and single line to ground fault is applied at point A in Fig.9 via a fault resistance of 0.2 Ω during the period 500-900 ms the voltage sag at the load point is 45% with respect to the reference voltage.

Similarly a new set of simulations was carried out but now with the D-STATCOM connected to the system as shown in Fig.10 where the very effective voltage regulation provided by the D-STATCOM can be clearly appreciated.

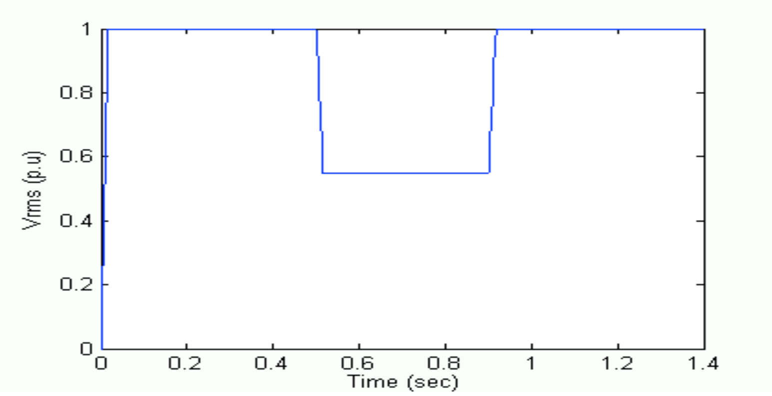

Fig.9 Voltage V_{rms} at the load point: without D-STATCOM

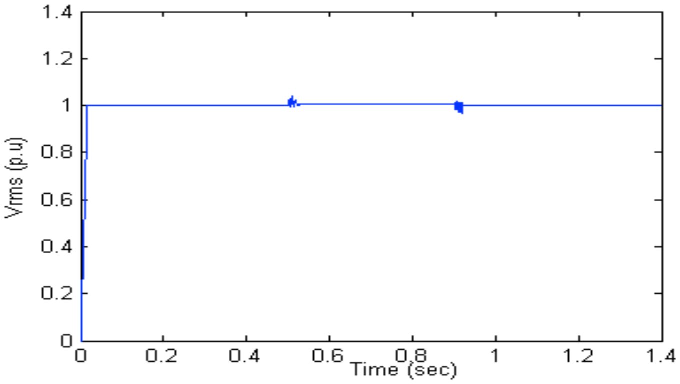

Fig.10 Voltage V_{rms} at the load point: with D-STATCOM energy storage of 20.9kv

Case2: Simulation result of voltage interruption during three phase fault

The first simulation contains no D-STATCOM and three phase fault is applied at point A. via a fault resistance of 0.001 Ω during the period 500-900 ms. the voltage at the load point is 0% with respect to the reference voltage is shown in Fig.11. Similarly a new set of simulation was carried out but now with the D-STATCOM connected to the system. The load voltage shown in Fig. 12.

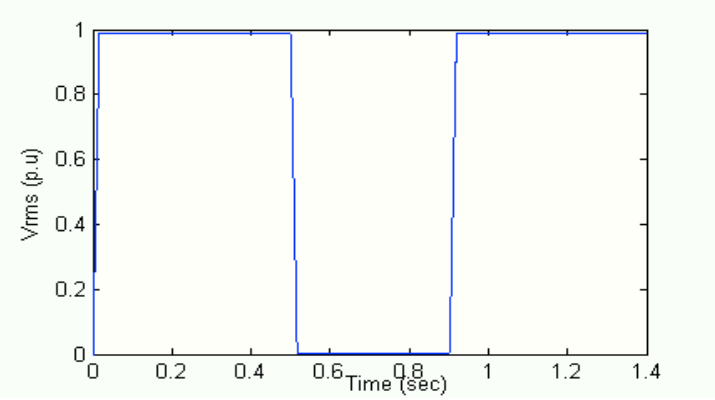

Fig.11 Voltage V_{rms} at the load point: without D-STATCOM

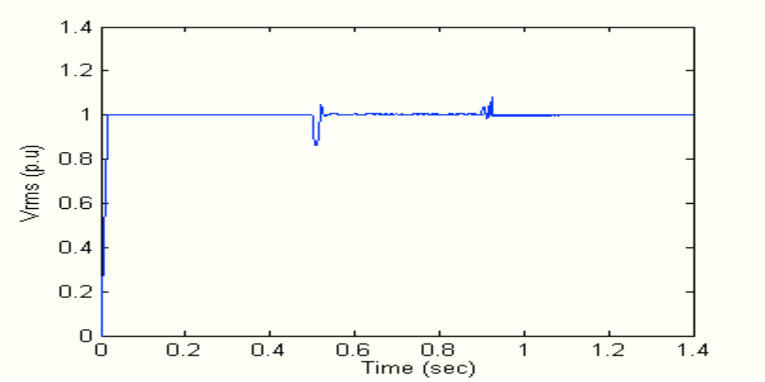

Fig.12 Voltage V_{rms} at the load point: with D-STATCOM energy storage of 40.7kv

Case3: Simulation results of voltage swell

The first simulation contains no D-STATCOM and three phase capacitive load applied at point A. during the period 500-900ms. The voltage swell at the load point is 10% with respect to the reference voltage is shown in Fig.13 and the test system for the simulation of D-STATCOM for swell is shown in Fig.14.

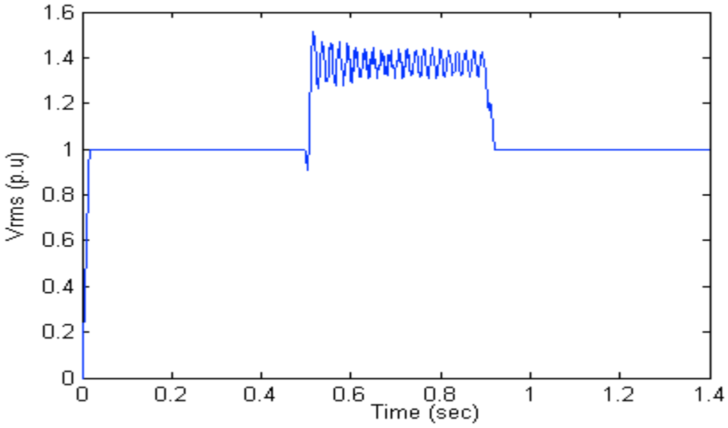

Fig.13 Voltage V_{rms} at the load point: without D-STATCOM

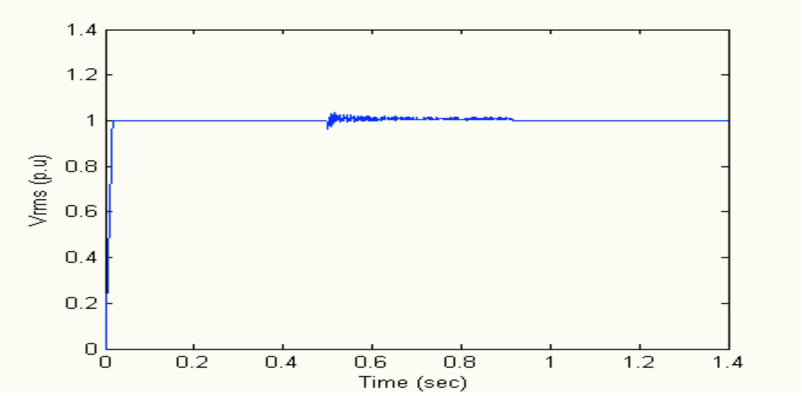

Fig.14 Voltage V_{rms} at the load point: with D-STATCOM energy storage of 16.8kv

3.2 *Simulation Results of DVR*

Case1: Simulation results of voltage sag during single line to ground fault

The first simulation contains no DVR and single line to ground fault is applied at point A in Fig.15 via a fault resistance of 0.2Ω during the period 500-900ms. The voltage sag at the load point is 30% with respect to the reference voltage. The second simulation is carried out using the same scenario as above but now with the DVR in operation. The total simulation period is 1400 ms.

When the DVR is in operation the voltage sag is mitigate almost completely and the rms voltage at the density load point is maintained at 98% as shown in Fig.16.

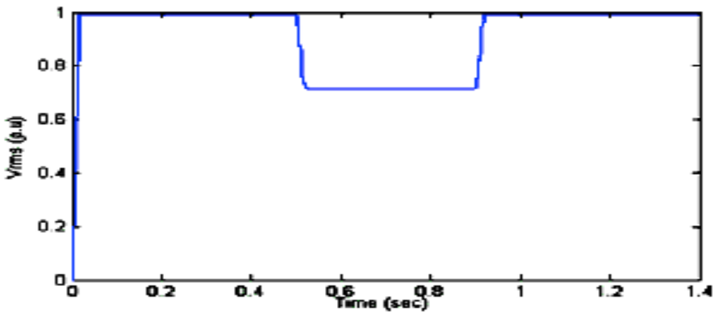

Fig.15 Voltage V_{rms} at the load point: without DVR

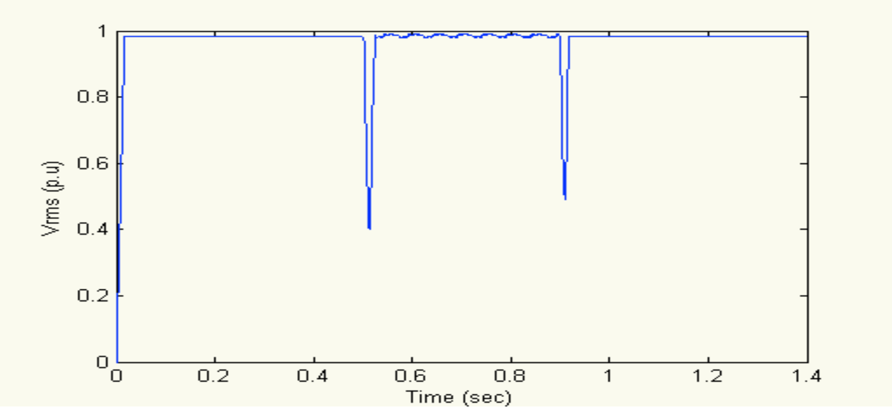

Fig.16 Voltage V_{rms} at the load point: with DVR energy storage of 7kv

Case 2: Simulation result of voltage interruption during three phase fault

The first simulation contains no DVR and capacitive load of is applied at load1. During the period of 500-900ms. The voltage swell at the load point is 25% with respect to the reference voltage.

The second simulation is carried out using the same scenario as above but now with the DVR in operation. The total simulation period is 1400 ms. Fig. 17 shows the rms voltage at the load point for the case when the system operates with no DVR. When the DVR is in operation the voltage swell is mitigated almost completely and the rms voltage at the sensitive load point is maintained normal.

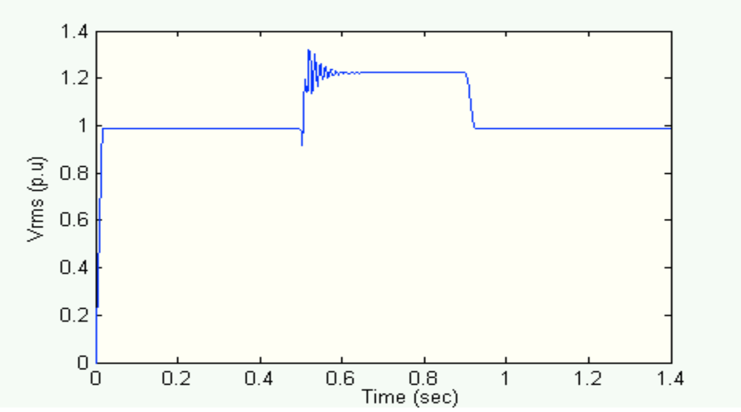

Fig.17 Voltage V_{rms} at the load point: without DVR

The PWM control scheme the magnitude and the phase of the injected voltages. Restoring the rms voltage very effectively. The swell mitigation is performed with a smooth, stable and rapid DVR response; two transient undershoots are observed as in Fig.18 when the DVR comes in and out of operation.

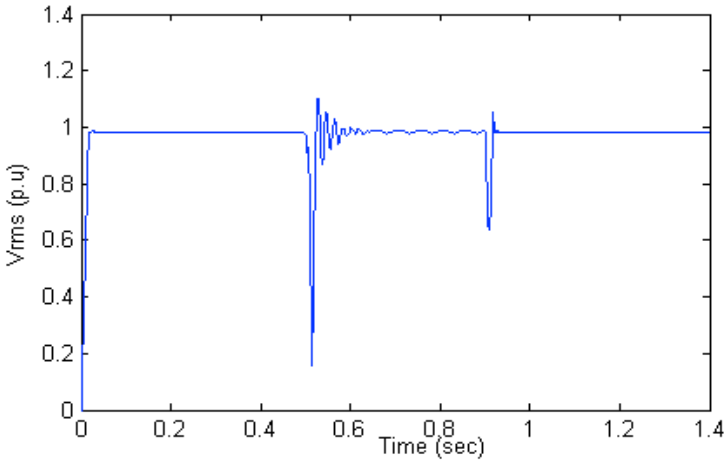

Fig.18 Voltage V_{rms} at the load point: with DVR energy storage of 6.8kv

Case3: Simulation result of voltage interruption during three-phase fault

The first simulation contains no DVR and three phase fault is applied at point A in Fig. 1 via a fault resistance of 0.001Ω doing the period 500-900 ms. The voltage at the load point is 0% with respect to the reference voltage. The second simulation is carried out using the same scenario as above but now with the DVR in operation.

The total simulation period is 1400 ms. When the DVR is in operation the voltage sag is mitigated almost completely, and the rms voltage at the sensitive load point is maintained at 98% as shown in Fig.20.

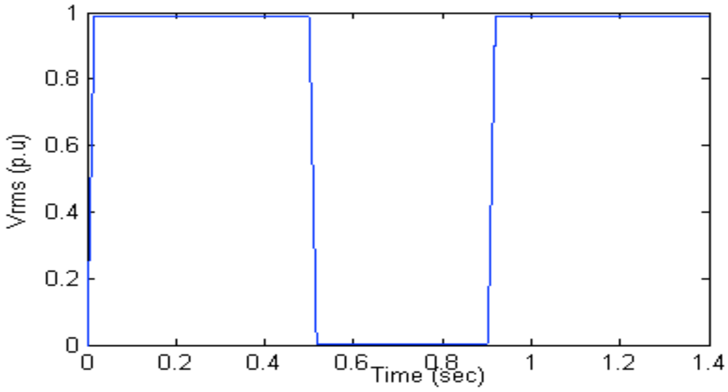

Fig.19 Voltage V_{rms} at the load point: without DVR

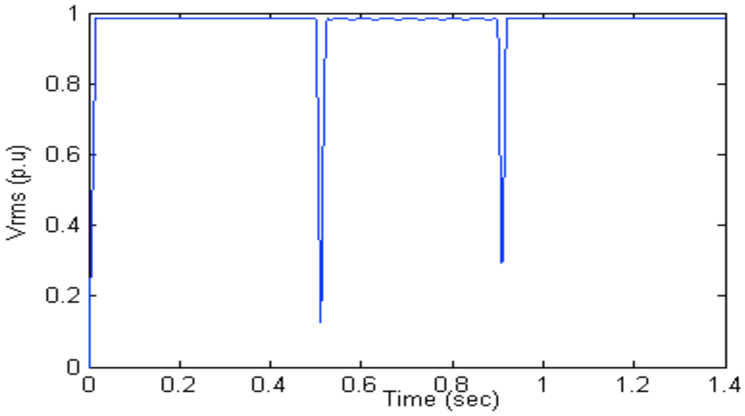

Fig.20 Voltage V_{rms} at the load point: with DVR energy storage of 4.9kv

4. Conclusion

This paper has presented the power quality problems such as voltage dips, swells and interruption consequences and mitigation techniques of custom power electronic devices DVR D-STATCOM and SSTS. This design and applications of DVR, D-STATCOM and SSTS for voltage sags. Interruptions and swells and comprehensive results are presented.

A new PWM based control scheme has been implemented to control the electronic valves in the two levels VSC used in the D-STATCOM and DVR. As opposed to fundamental frequency switching schemes already available in the MATLAB/SIMULINK this PWM control scheme only requires voltage measurement.

This characteristic makes it ideally suitable for low voltage custom power applications. The simulations carried out showed that the DVR provides relatively better voltage regulation capabilities. It was observed that the capacity for power compensation and voltage regulation of DVR and D-STATCOM depends on the rating of the de storage device.

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