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# Enhanced StatCom and Adaptive Neuro Fuzzy Logic Control at Grid Integrated FSIG Type Wind Farms under Asymmetrical Fault Condition

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## *Abstract*

***StatCom which is a shunt compensator is used to improve the stability of fixed speed induction generator based wind turbines for balanced grid voltage dips. Voltage dips during unbalanced grid conditions cause heavy generator torque oscillations due to the negative sequence voltage. This reduces the lifespan of the drive train. This project focusses on researching the effect of unbalanced grid voltage fault on a grid connected FSIG based wind farm with StatCom. This research is carried out by means of theory, simulations. A StatCom control unit is designed which is used to coordinate the control between the positive and negative sequence components of the grid voltage. The simulation and analysis verify the effects of voltage compensation by StatCom both positive and negative sequence components on the operation of FSIG based wind farm. The compensation of the positive sequence voltage is given the first priority by StatCom. This gives the maximum fault ride through enhancement of the windfarm. Next, the torque oscillations which are caused by the negative sequence voltage are reduced by controlling the current capability of the StatCom.***

***In order to further enhance the performance and increase the voltage stability we have used ANFIS (Adaptive Neuro Fuzzy Interference System) to decrease the voltage dip and minimize the errors due to PI controllers in StatCom controller structure. The theoretical analysis are ensured through simulation***

*Index Terms –* ***FSIG (Fixed Speed Induction Generator), LVRT (Low Voltage Ride Through), StatCom, Positive and Negative Sequence Components of Voltage, Wind energy, Asymmetrical fault***

## INTRODUCTION

This thesis is made to investigate and create a StatCom compensated FSIG based wind farm. The system's primary purpose is to reduce the generator torque oscillations caused by negative sequence voltage under unbalanced grid conditions. A simulation model is designed to verify the mentioned points using SIMULINK of MATLAB. The assumed project is an approach to mitigate the day-to-day problems of fixed speed induction generators within wind farms. Further, the enhancement done by Adaptive Neuro Fuzzy Logic Controller system is used to uplift the operating capability of the system arrangement and improve voltage stability.

Now-a-days a major chunk of wind farms employ variable speed wind farms which use any of the two :- a) DFIG (doubly fed induction generator) or b) PMS (Permanent Magnet Synchronous) generator. Yet 15% of operating wind farms which were previously installed are of grid-connected FSIG (fixed speed induction generators) type.

These kind of generators cannot do self-reactive power compensation. Hence they cannot adhere to the existing norms of grid-requirements without the use of compensating devices.

Induction generators are basically induction motors whose prime-mover's speed is greater than the synchronous speed. When the applied torque of the generator's shaft by the prime-mover increases, the power output of the induction generator increases. The torque vs speed characteristic of the induction machine is as given below shows,

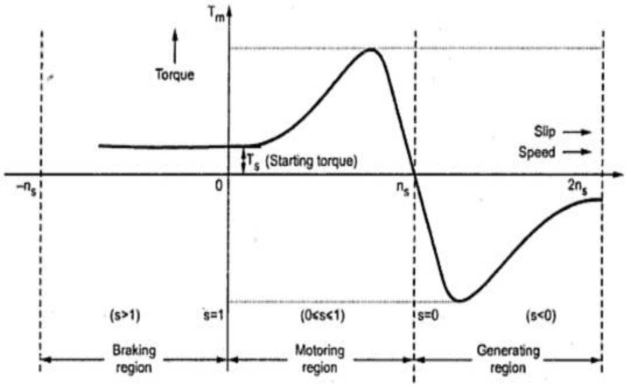


Fig. 1 The torque vs speed characteristic of an induction generator

Pushover torque of the generator is the maximum possible induced torque applied to the machine when operating in the generator mode of operation. If the applied torque on the shaft of an induction generator exceeds the pushover torque of the prime mover, the generator will over-speed.

There are several disadvantages of an induction generator. As the induction generator doesn't have an individual field circuit, it cannot do reactive power compensation. An external source must do reactive power compensation perpetually for an induction generator. This reactive power compensation by an external source should also control the generator's terminal voltage. An induction generator is unable to control its own terminal voltage due to the absence of field current. Usually, the external source of power arrangement to which the generator is connected maintains the generator's voltage.

The greatest advantage of an induction generator is its simplicity. As there is not the necessity of a separate field circuit and it is not necessary to drive it at fixed speed continuously induction generators are more employable. The only requirement of an induction generator is that the machine should run at some speed greater than the synchronous speed. The induction generator's power output can be increased by merely increasing the torque applied to its shaft (till a breaking point). Induction generator is a smart choice for windmills, heat recovery systems and supplementary power banks because no fancy regulation arrangement is required to make the generator work. While capacitors, SVCs can help in power factor correction of an induction generator and can also control the generator's terminal voltage, StatCom is preferred. This is because while SVCs employ only capacitors to provide reactive power, StatComs have both capacitor banks and inductor banks to provide reactive power and absorb reactive power respectively.

Further ANFIS (Adaptive Neuro Fuzzy Interference System) is used to enhance the system performance and improve the system stability.

## PROBLEM DEFINITION

This project researches upon the StatCom's application when it is connected to a FSIG wind farm. It verifies how a StatCom controls the positive and negative sequence voltage components during unbalanced grid faults. The prime purpose of the project is to achieve voltage control through coordination between both the components of the voltage and the related effect on the behavior of the wind turbine. The secondary purpose is enhancement of the system by ensuring voltage stability through adaptive neuro fuzzy logic control of the StatCom. This further improves the performance of the system. The compensation of the positive sequence component of the voltage results in complete stability of the voltage of the wind farm and the compensation of the negative sequence component of the voltage results in reduction of torque oscillations which increases the lifespan of the drive train.

## OBJECTIVES OF THE PROJECT

### The project objectives are:

- To control the dynamic stability of FSIG based windfarm.
- Compensation of positive and negative sequence components of voltage individually by coordination between the components.
- To improve voltage stability of the system due to voltage dips during unbalanced grid faults.
- To dampen the torque ripple.
- To meet the grid specifications during grid faults.
- To ensure high power quality.
- To improve the performance by using adaptive neuro fuzzy logic and verify it.

## POWER SYSTEM ARCHITECTURE

## SYSTEM REQUIREMENT

| SYSTEM REQUIREMENT | CONFIGURATION |
|---|---|
| Operating System | Windows 10 |
| Processor | Quad core |
| Instruction set | 64 bit |
| Speed | 1.8 GHz |
| Package | MATLAB 2013 and higher |
| Framework | SIMULINK |
| RAM | 4 GB |
| Hard Disk | 160 GB |
| Keyboard | Standard Windows Keyboard |
| Mouse | Two or Three Button Mouse |
| Monitor | SVGA |

Table. 1 System Requirement

| Sl. No. | Windfarm Induction Generator | Simulation Parameters |
|---|---|---|
| 1 | Base Apparent Power | 57.5 MW |
| 2 | Rated Active Power | 50 MW |
| 3 | Rated voltage (line to line) | 690 V |
| 4 | Stator Resistance () | 0.0108 p.u. |
| 5 | Stator Stray Impedance () | 0.107 p.u. |
| 6 | Mutual Impedance () | 4.4 p.u. |
| 7 | Rotor Resistance () | 0.01214 p.u. |
| 8 | Rotor Stray Impedance ( | 0.1407 p.u. |
| 9 | Compensation capacitors | 0.17 F |
| 10 | Mechanical time constant | 3 s |

Table 2 Windfarm Induction generator simulation parameters

| Sl. No. | StatCom | Simulation Parameters |
|---|---|---|
| 1 | Rated Power | 50 MVar |
| 2 | Rated Voltage | 690 V |
| 3 | Line filter (*L filter)* | 0.15 p.u. |
| 4 | *L Netz* | _ |
| 5 | DC Voltage () | 1200 V |
| 6 | Current Capability | 1 p.u. |

Table 3 StatCom simulation parameters

| Sl. No. | Constraint | Grid | HV Transformer | MV Transformer |
|---|---|---|---|---|
| 1 | Base Apparent | 1000 MW | 100 MW | 100 MW |
| 2 | Power Rated Voltage | 110 kV | 30 kV | 690 V |
| 3 | Stray Impedance () | 0.98 p.u. | 0.05 p.u. | 0.1 p.u. |
| 4 | Resistance () | 0.02 p.u. | 0.01 p.u. | 0.02 p.u. |

Table 4 Simulation parameters of grid and transformers

## SYSTEM TOPOLOGY

## EXISTING SYSTEM

After an analysis of the base paper by **C.Wessels, N. Hoffman, M. Molinas and F.W. Fuchs** the detailed topology of the existing system is given below.

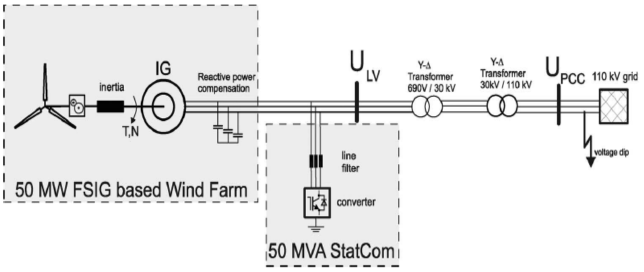


Fig. 2 Topology of the existing system

The figure below shows the simulation model of the existing system. It shows 50 MW windfarm employing induction generator connected to the grid directly; a 50 MVA StatCom structure connected to the grid directly as well as to the wind farm. By the use of a typical T-equivalent circuit the windfarm is modeled as an aggregate model i.e. the generator is an aggregate sum of all the turbines. The StatCom shown in the figure is modeled as voltage controlled source. The induction generator as well as the StatCom are connected to the low voltage busbar and then a transformer is used to connect them to medium voltage busbar. The second transformer connects them to high voltage busbar. Both the transformers are rated for the sum of ratings of generator and StatCom. The first transformer has a series impedance of 5% p.u. while the second one has a series impedance of 10% p.u. The grid fault is supposed to strike at the high voltage busbar and this is modeled as Thevenin equivalent. Since the project focusses on unbalanced grid voltage dips which create generator torque oscillations thereby resulting in instability of the voltage source. This affects the lifespan of the drive train of the wind farm.

Thus StatCom is used as a shunt device which ensures stability between the positive and negative sequence components of the voltage. Continuous DC supply is fed to the positive sequence and the StatCom removes the distortion causing AC components.

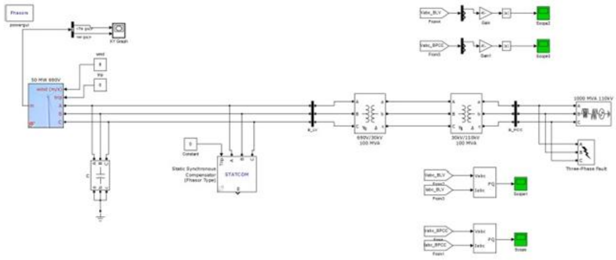


Fig. 3 Simulink model of existing system

A StatCom controller structure to coordinate between positive and negative sequence voltage components is also mentioned in the paper.

## PROPOSED SYSTEM

The proposed system has these features in addition to the existing system:-

### Design of GSC Controller:

GSC is Grid Side Converter. The DC bus voltage is maintained at a constant value by the GSC. The primary concern of the GSC is to maintain unity power factor of the converter. This is realized as the converter can control the reactive power. The current flowing within the converter is minimized as a result of this.

### Design of RSC Controller:

The machine speed along with the reactive power being supplied through the machine stator can be controlled by Rotor side Converter (Inverter). The primary concern of the rotor inverter is controlling the speed of the generator within a range of wind velocities so as to achieve maximum power from the wind. The rotor side converter (inverter) control scheme basically consists of a multi-level structure that consist of a speed controller, an active power controller, a reactive power controller and current control loop. It is worth mentioning that by realizing decoupled current control the power control loop can be omitted.

### Fault-ride through capability:

Low Voltage Ride Through (LVRT) and High Voltage Ride Through (HVRT) capabilities are quintessential for Direct Energy Systems (DER). Micro-grids are prone to direct transition from grid-connected mode of operation to autonomous mode during faults. This must be suppressed either in accordance with the LVRT curve or HVRT minimum no. of trips.

Otherwise, the main principle of Fault Ride Through (FRT) (i.e. preventing sudden generation loss) is vanished. The transition of the mode of operation from grid-connected to autonomous should only take place if the span of disturbance is too long.The proposed system assures that the micro-grid controller responsible for transition during faults is designed according to these transition constraints.The chosen architecture in a micro-grid plays an essential role in fulfilling FRT requirements. The architecture also influences the internal bus configuration of a micro-grid.Power quality issues are thoroughly analyzed and hence the system is designed keeping them in view.

The StatCom control structure along with the StatCom connected at PCC can improve the LVRT capability of the FSIG grid connected wind farm as well as ensure smooth transition during faults. It can also counter voltage sag and voltage swell within permissible limits and thereby keep the torque oscillations in limits and improve dynamic stability by coordinating between positive and negative voltage components.Voltage sag can be defined as a dip in the rms value of the voltage from 0.1 to 0.9 p.u. at the grid frequency for time durations starting from half cycle to a minute. The main reasons are grid faults, heavy loads and turning on of large inductive loads like large motors.Voltage swell is defined as a rise in the rms value of the voltage from 1.1 to 1.8 p.u. at the grid frequency for time durations starting from half cycle to a minute. Voltage swells occur less frequently than voltage sags.

Also the main cause of voltage swells is bringing the capacitor banks into operation. Also the frequency of occurrence of unsymmetrical faults is greater in a three-phase system than in symmetrical faults.

### Fault Ride-Through Performance Topologies:

There are two (2) topologies of wind farms: - **DFIG** (Doubly Fed Induction Generator) and **FSIG** (Fixed Speed Induction Generator). FSIG is chosen over DFIG because of two major disadvantages of the latter:

- DFIG is very susceptible to power quality issues especially to voltage disturbances like voltage sags. Moreover, due to this sensitivity if any grid fault occurs this leads to large uncontrollable current in the RSC thereby damaging the power electronic components.
- DFIG is more prone to output power flicker.

Furthermore, the topologies like (i) Passive Methods like DC chopper and (ii) Active Methods of solving power quality issues are taken into consideration.

### Constant Power Loads in Grid Integrated Wind farms:

The operational stability when the marriage of Distributed Generation (DG) with Low Voltage (LV) takes place is only maintained when the generation system stays in grid connected mode during voltage sags. The fixed speed squirrel cage induction generator (FSIG) associated wind turbines are incapable of providing effective reactive power and the DG needs a good compensating device. Whenever there is an asymmetrical grid fault the circulation of negative sequence flux within the air gap generates torque oscillations. This in turn reduces the lifespan of the generator.

Hence in the proposed system the StatCom is the effective compensating device. Moreover the StatCom control structure compensates the negative sequence flux and hence reduces torque oscillations.

### Incorporation of ANFIS into the proposed system:

The steps to incorporate Anfis in the proposed system are: -

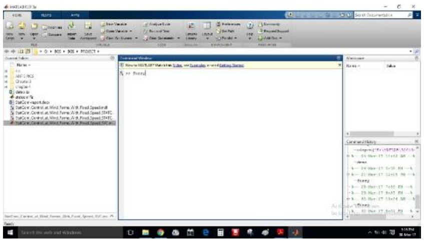
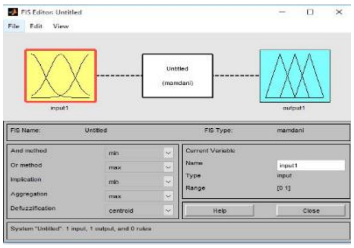
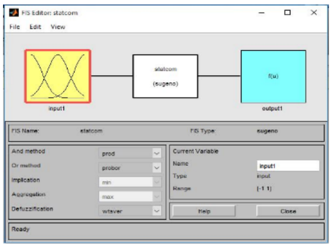


Fig. 4 Opening FIS editor



FIS Name: Untitled
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: input1
Type: input
Range: [0 1]
System "Untitled": 1 input, 1 output, and 0 rules

Fig. 5 Opening Input block of the FIS editor



FIS Name: statcom
FIS Type: sugeno
And method: prod
Or method: probor
Implication: min
Aggregation: max
Defuzzification: wtaver
Current Variable
Name: input1
Type: input
Range: [-1 1]
Ready

Fig. 6 Import StatCom fis file

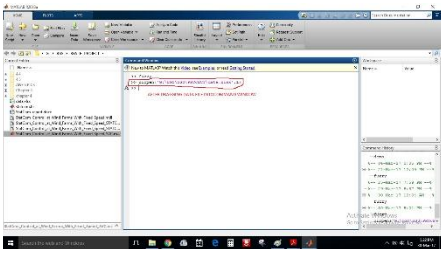


Fig. 7 After dragging data file into Command window

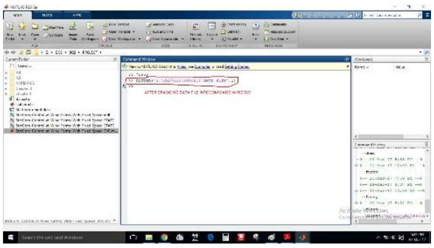


Fig. 8 Data dialog window appears

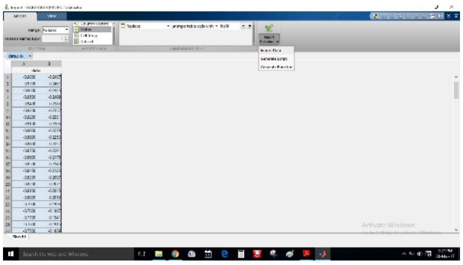


Fig. 9 Importing data

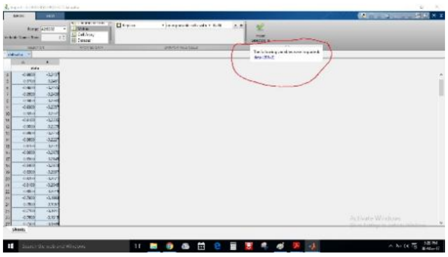


Fig. 10The imported variables

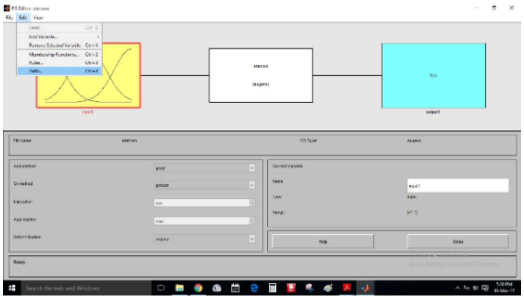
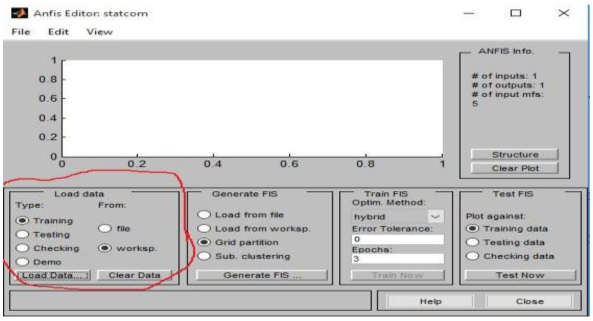


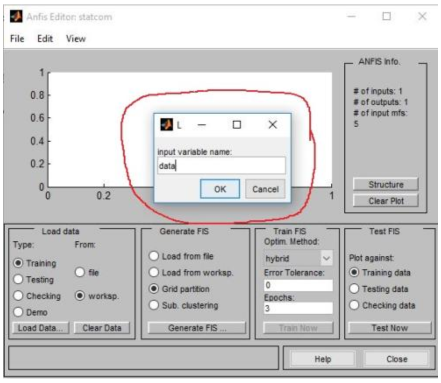
Fig. 11 Selecting Anfis



# of inputs: 1
# of outputs: 1
# of input mfs:
5

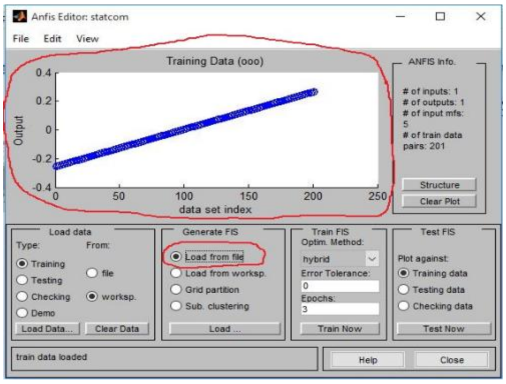
Optim. Method: hybrid
Error Tolerance: 0
Epochs: 3

Fig. 12 How to load data onto Anfis editor



input variable name:
data

Fig. 13 Entering Input Variable Name

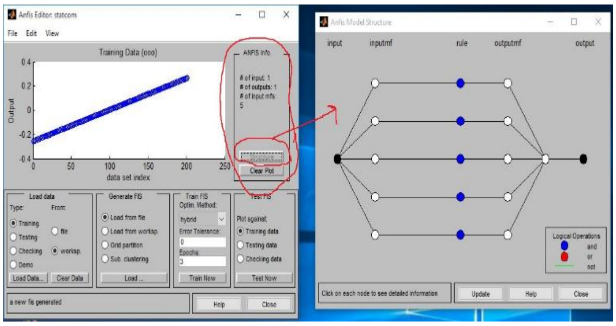


# of inputs: 1
# of outputs: 1
# of input mfs:
5
# of train data pairs: 201

Optim. Method: hybrid
Error Tolerance: 0
Epochs: 3

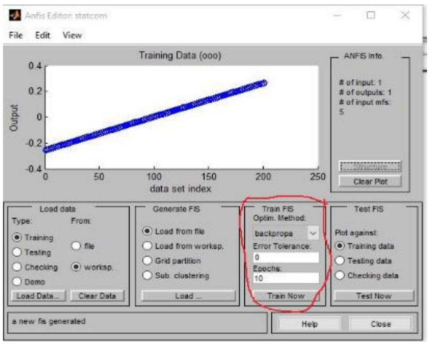
train data loaded

Fig. 14 Training data



a new fis generated

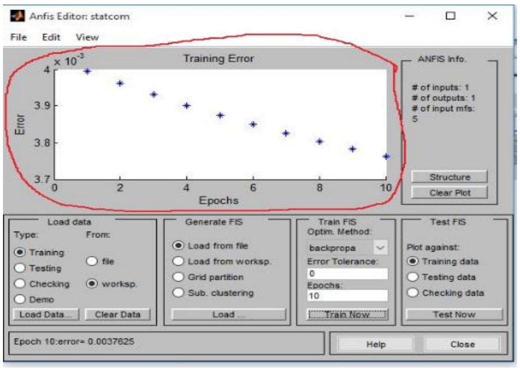
Fig. 15 Anfis Model Structure



Optim. Method: backpropa
Error Tolerance: 0
Epochs: 10

a new fis generated

Fig. 16 How to train FIS.



# of inputs: 1
# of outputs: 1
# of input mfs:
5

Optim. Method: backpropa
Error Tolerance: 0
Epochs: 10

Epoch 10:error= 0.0037625

Fig. 17 Trained data error

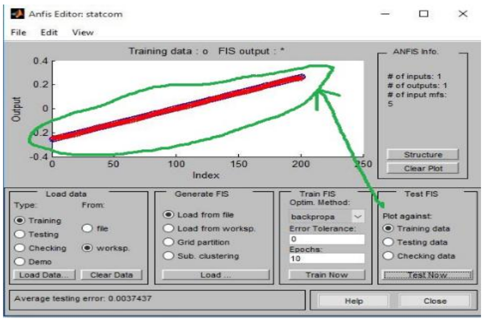


Fig. 18 Trained data (red) versus PI controller data (blue)

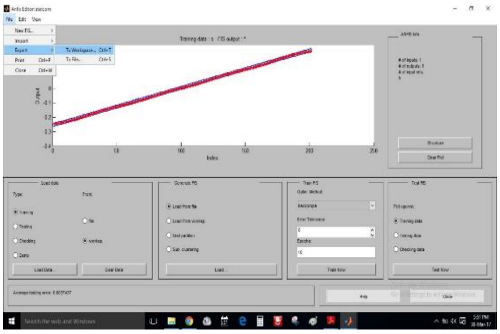


Fig. 19 How to export to workspace

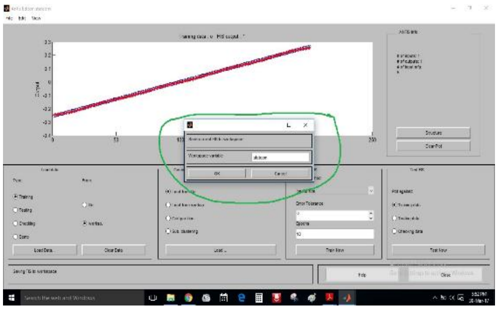


Fig. 20 How to save to workspace

- Type fuzzy on command window and open the FIS editor (fig. 4)
- Click on Input block of the FIS editor (fig. 5)
- Then we click on Import under File drop down menu. And we Import - > From File - > StatCom(fis type file) (fig. 6)
- Then we drag the data file into the command window (fig. 7,8)
- Then we click Matrix above Imported data from Import Selection (Fig. 9)The fig. 10 shows the variables which were imported.
- Then we go to FIS editor: StatCom and click Anfis from Edit drop down menu (fig. 11).
- The ANFIS editor: StatCom is opened. Under Load Data block we click on Training and Workspace and then Load Data(fig. 12).

We click on Load Data and then the Input Variable Name is asked. We enter data. (Fig. 13).

- After entering data, the blue line represents Training Data.Under the Generate FIS block we click Load From File (fig. 14)After clicking load we select StatCom fis file.
- On the right side we have ANFIS info. We click on Structure tab and then Anfis Model Structure dialog window appears (fig. 15)
- Under the Train FIS block and under Optimum method we select back propagation and give Error Tolerance as 0 and Epochs as 10 and click Train Now.(fig. 16)

After clicking Train Now we get blue colored Trained data error (fig. 17)

- Under Test FIS we select Training data and click Test Now (fig. 18)
- Fig. 19 shows how to export to workspace. Fig. 20 shows how to save to workspace.And then we click Ok.
- And then we view Rules from View menu.Fig. 21 shows that green Anfis data is more stable than blue PI controller data.

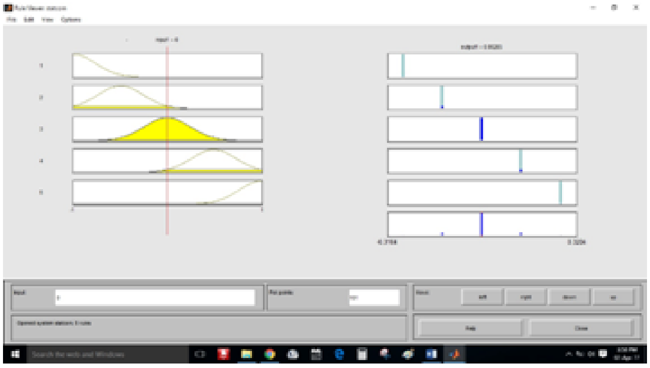


Fig. 21 Rule Viewer of StatCom fis file

After compiling the data we see in scopes that the green line representing Anfis data is stable than red line representing PI data.

## WORKING PRINCIPLE BASIC OVERVIEW

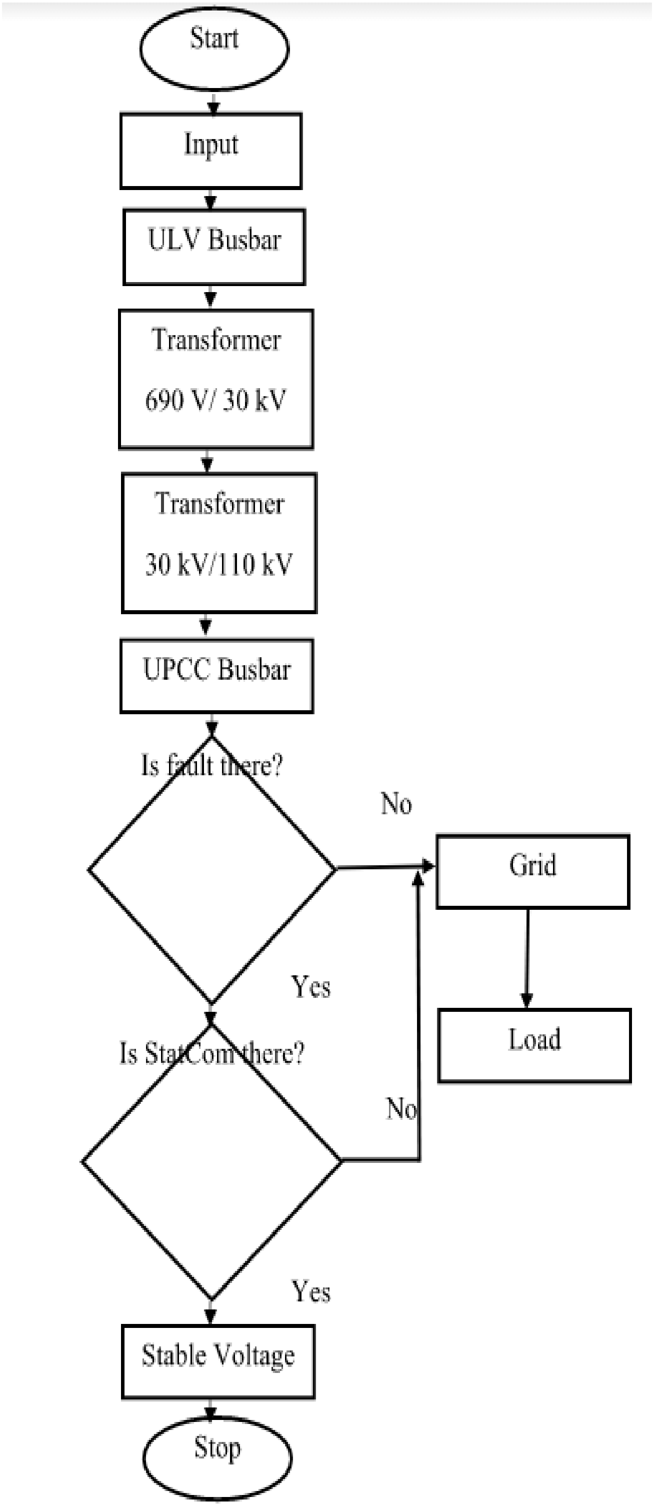


Fig. 21 Flow chart of the working principle of the proposed system

## HOW DOES STATCOM CONTROLLER ALONG WITH ANFISWORK?

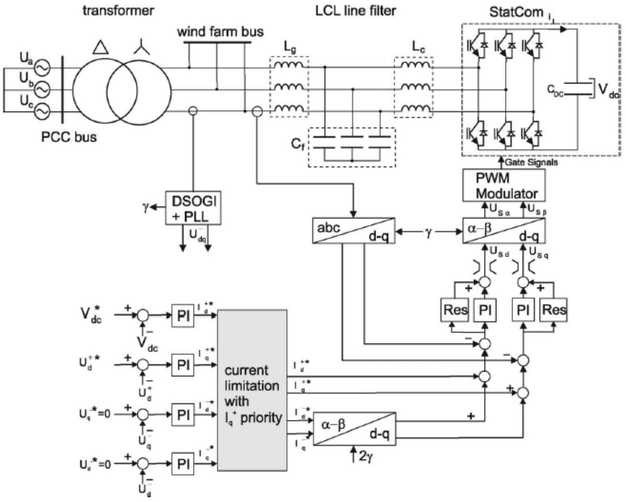


Fig. 21 StatCom control structure for controlling positive and negative sequence voltage components

StatCom control structure is primarily revolves around the voltage oriented vector control scheme. This is usually applied to the three grid connected converters. The StatCom control structure is step by step cascaded control structure. It internally consists of PI (Proportional Integral) current controllers which rotate in a dq reference frame. The PI controllers have orientation with grid voltage.

PI controller's transfer function is given below: -

$$G_{PI}(s) = V_R \frac{1 + s.T_n}{s.T_n}$$

The controller gain design along with the modeling of voltage–oriented controlled three-phase type grid-connected inverters are explained and described.

In order to enhance the current the current control of negative sequence component, the resonant controllers are added to the same positive dq reference frame and are tuned at 100 Hz.

$$G_{Res}(s) = K_{res} \frac{s}{s^2 + (2.\omega_o)^2}$$

It is noteworthy that PI controllers can control the negative-sequence currents in a negative rotating reference frame but the sequence separation of currents is non-essential if in a positive rotating reference frame we use resonant controllers.

The StatCom control structure shown here is a grid-connected two-tier level VSC. A LCL filter connects it to the grid. For high-power applications multi-tier structures can be used.The control loops at the outer end control the positive and negative sequence components of the StatCom as well as the dc voltage at the point where the StatCom is connected to the grid. Dual second-order integrators perform accurate sequence separation of the voltage measured. We can also apply any kind of sequence separation methods. After separation of the sequence components the positive and negative sequence components of the measured voltage appear as dc values and PI controllers can effectively control them. The reference current of the outer four controllers is set at the maximum StatCom current. This ensures the operation of the StatCom within a safe operating range. The first priority is given to $I_q +$ ; the positive sequence component of the reactive current. Hence maximum FRT (Fault Ride Through) performance of the wind farm is ensured by the StatCom. This takes place by compensation of positive sequence voltage.Whenever asymmetrical grid faults take place, the torque ripple needs to be reduced which occurs due to the negative sequence component of voltage. In order to achieve this, the StatCom is controlled by the remaining current capability of StatCom control structure.Both the components of current references i.e. the positive and negative sequences must be added. For the transformation of positive sequence current into negative sequence current a transformation of coordinates takes place by doubling the grid voltage angle. The paper doesn’t focus on smoothening the torque transients or finding a control strategy for the same. It is noteworthy that the control strategy doesn’t compensate for the transient torques at the starting and at the elimination of the grid fault.For investigating the effect of unsymmetrical grid faults on the operating capability of induction generators we take into consideration various control targets for effective compensation of the positive and negative sequence voltage components. In first method the aim is to keep the negative sequence voltage unchanged and compensation of the positive sequence voltage. In the second method the aim is to nullify negative sequence voltage keeping the positive sequence voltage unchanged.

## RESULTS

A grid voltage dip due to an unsymmetrical grid fault and its effect on the working of the induction generator and its stabilization by the usage of StatCom.

An unsymmetrical grid fault and an accompanying voltage up to 50% of the voltage amplitude is supposed to take place at the $B_{PCC}$ (high voltage busbar) of the system. Fig. 22 shows this.

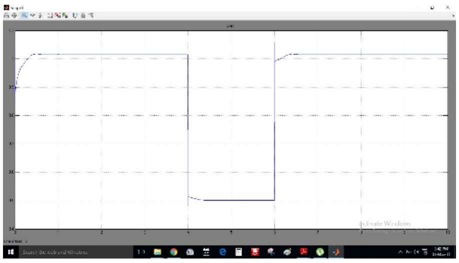


Fig. 22 Unbalanced grid fault without

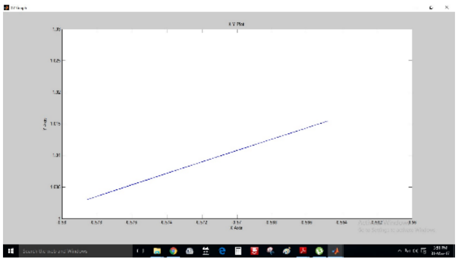


Fig. 23 Voltage drop versus time without StatCom compensation by StatCom

Fig. 23 shows the sudden dip in voltage without the use of StatCom.

Due to a decrease in positive sequence voltage there is a decrease in mechanical torque and hence the rotor accelerates. The most striking difference between asymmetrical and symmetrical grid fault is that asymmetrical grid faults cause heavy torque oscillations within the system which are caused due to the negative sequence component of the voltage.

In this simulation, it is seen that there is no voltage instability within the system due to the occurrence of asymmetrical grid fault. This is because the generator returns back to the operating point after fault clearing but undoubtedly the system's mechanical parts are subjected to heavy stress due to mechanical torque oscillations.

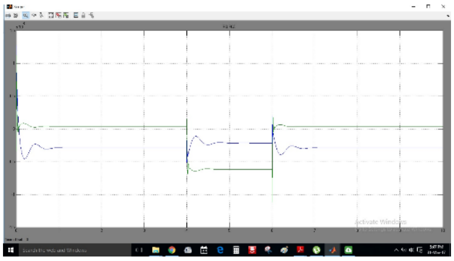


Fig. 24 Compensation by StatCom

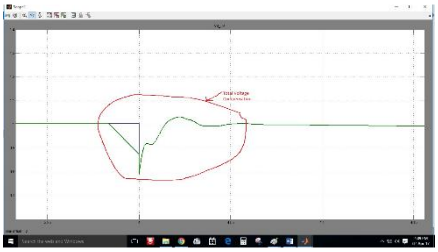


Fig. 25 Total voltage compensation at the low voltage bus bar.

In the middle of Fig. 24 it is seen that the simulation results show how compensation by StatCom changes the grid fault.The blue line indicates grid power after fault and here the compensating device is a plain capacitor.The green line indicates grid power after fault and here the compensating device is a StatCom.The StatCom does compensation of the positive sequence component of the voltage. The StatCom's current rating is chosen to be 1 p.u. At this rating the positive sequence component of the voltage can be totally compensated by a StatCom. The fig. 24 shows this. This is achieved by injection of a positive-sequence StatCom current.

Fig. 25: The green line shows the negative sequence component of voltage. The current injected is totally reactive current. Since the negative sequence component of voltage remains uncontrolled hence it stays unaffected.

Fig. 26 :From the XY graph below it is seen that the speed doesn't increase since after the compensation of positive sequence component of voltage, the generator acquires complete torque capability. However there are still high torque oscillations due to negative sequence component of voltage. Hence the StatCom is used to eliminate the negative sequence component of voltage. This elimination can only take place by injection of a negative sequence current via StatCom controller. This injection must take place into the grid.

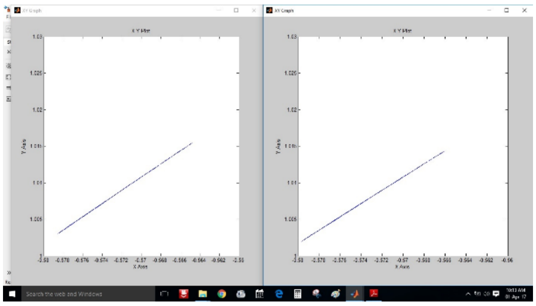


Fig. 26 LHS: - Torque vs. Speed without StatCom
RHS: - Torque vs. Speed with StatCom

This technique of injection of StatCom current into the grid completely eliminates the negative sequence component of voltage and hence reduces heavy torque oscillations and as a result unbalanced grid fault too is eliminated.But it is noteworthy that since the compensation of positive-sequence component of voltage doesn't happen its amplitude continuously decreases due to reactive power consumption. But since the generator doesn't become unstable, it returns back to its normal operation after elimination of the grid fault. However there is a drawback of this strategy and it is the continuously oscillating active and reactive powers by the StatCom. While sizing the StatCom we must take into consideration the high frequency components in active power.Without the presence of StatCom as the generator starts accelerating, this eventually leads to high torque oscillations.In the reverse process, when the StatCom

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injects positive sequence current, the StatCom compensates for the voltage dip in positive sequence component. This ensures that the generator doesn't accelerate but as the negative-sequence component of voltage is not compensated the generator torque oscillations are not eliminated.This section helps us in understanding StatCom voltage control and hence the operation of the FSIG at the occurrence of an unsymmetrical grid fault.When the StatCom does compensation of the positive sequence component of voltage, the torque capability of the FSIG increases and generator acceleration during asymmetrical grid fault and accompanying voltage dip can be eliminated.When the StatCom does compensation of the negative sequence component of voltage, the unbalanced component of voltage, FSIG's torque oscillations get significantly reduced.The performance of the StatCom and its ability to do voltage control is dependent upon the StatCom's current rating and the power system's impedance. This implies that if the StatCom is rated for higher current values and the power system is weak (due to large impedance of the power system), the StatCom does better voltage compensation.

The figures 27 to 30 compare the plots and graphs amongst these three models: -

- Compensation just by a capacitor
- Compensation by a StatCom
- Compensation by Anfis incorporated StatCom

The fig. 27shows that by enabling StatCom compensation the slope of the graph is not steep and hence there is less acceleration of FSIG.

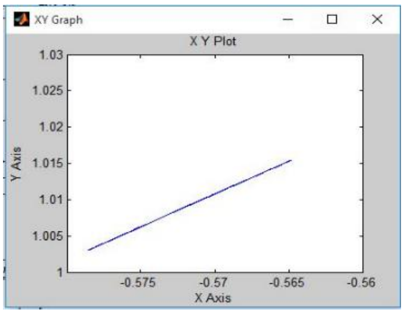

Fig. 27 I

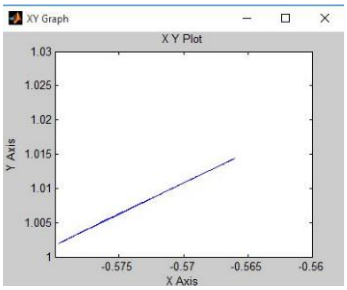

Fig. 27 II

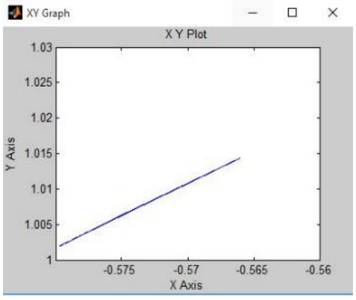

Fig. 27 III

Fig. 27 Generator torque vs. speed graphs for the three models

Fig. 28 shows that by enabling a StatCom the transients at the point of occurrence of voltage dip due to unsymmetrical grid fault can be smoothened. By incorporating Anfis the errors get reduced and hence the voltage appears more smoothened without any kink.

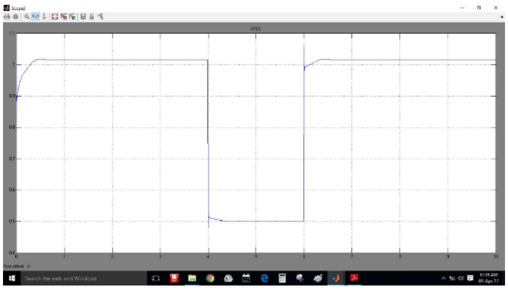

Fig. 28 I_a

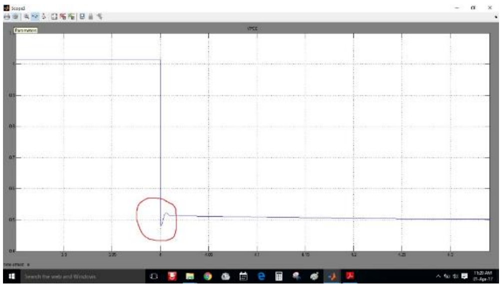

Fig. 28 I_b

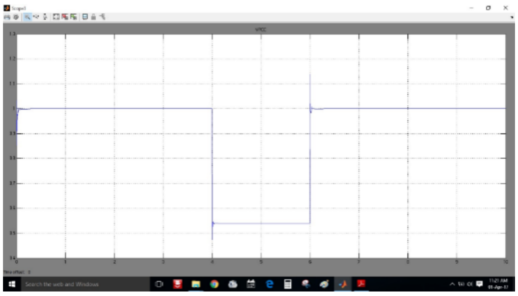

Fig. 28 II_a

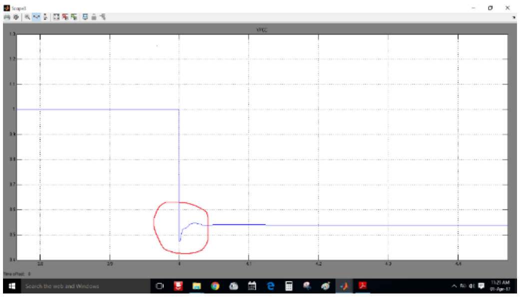

Fig. 28 II_b

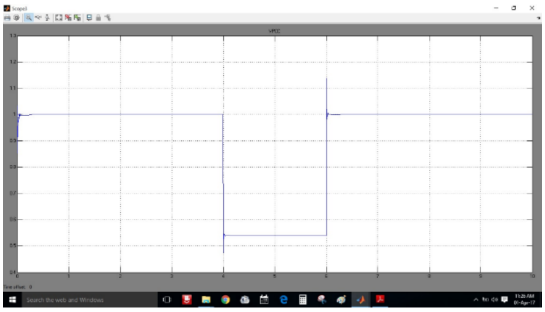

Fig. 28 III_a

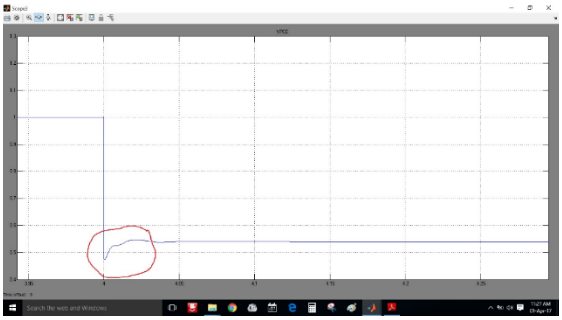

Fig. 28 III_b

Fig. 28 Voltage in high voltage busbar at the occurrence of unsymmetrical grid fault
I,II,III: - as per convention
a:- Voltage dip in autoscale mode
b:- voltage dip in enlarged mode

The figures in 29 show the voltage dip in low voltage busbar after compensation.

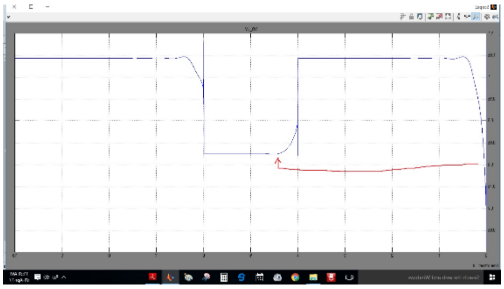

Fig. 29 I_a

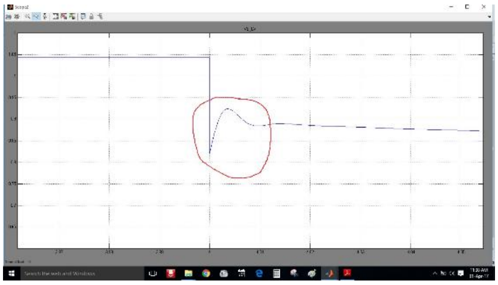

Fig. 29 I_b

The fig. 29 I_a shows that the dip from high voltage busbar has been significantly reduced after compensation by a plain capacitor in low voltage busbar as its amplitude is nearly 0.85 instead of 0.5 as in $B_{PCC}$ just before compensation. The fig. 29 I_b is fig. 29 I_a enlarged and it shows that although the dip has reduced the transient has not smoothened and there are kinks.

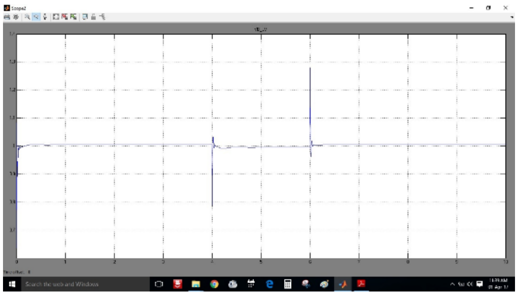

Fig. 29 II_a

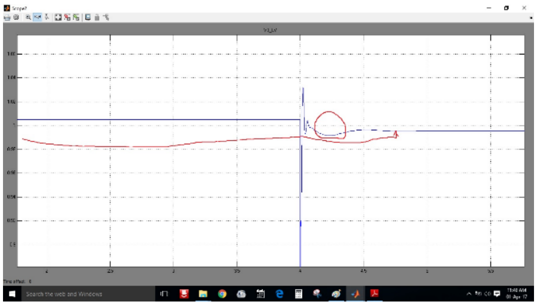

Fig. 29 II_b

The fig. 29 II_a shows that due to compensation by StatCom the voltage dip is almost nullified in low voltage busbar.The fig. 29 II_b is fig. 29 II_a is enlarged and it shows that the voltage dip is 0.99 due to compensation by StatCom as against 0.85 due to compensation by capacitor in the low voltage busbar.Also since the StatCom is enabled to inject negative sequence current, only voltage compensation takes place however oscillations are only reduced but not completely eliminated.

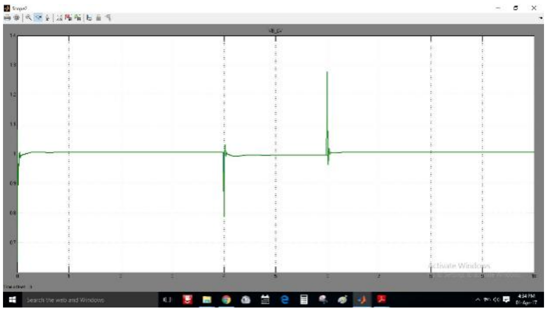

Fig. 29 III_a

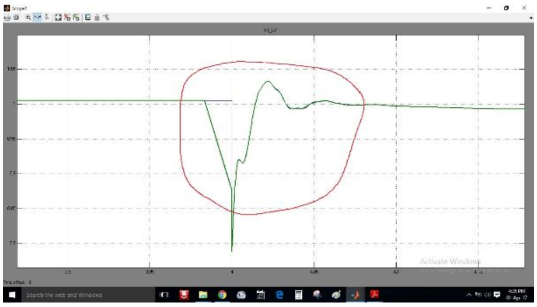

Fig. 29 III_b

Figures 29 :- Voltage dip in low voltage busbar ($B_{LV}$)

It is seen from fig. 29 III_a that by enabling Anfis incorporated StatCom, the voltage dip is completely nullified. The green line represents trained data for epochs in Anfis. The green line is more stable than blue.After elongating fig. 29 III a along X and Y axes it is seen that the dip is almost nullified, the transients are smoothened however the oscillations are still present.

Fig. 30 shows the comparison of active power (green line) and reactive (blue line) between high voltage busbar ($B_{PCC}$) and low voltage busbar ($B_{LV}$). The 30 I_a, 30 II_a, 30 III_a figures show that due to absence of reactive power compensation, the active and reactive powers are negative. The 30 I_b, 30 II_b, 30 III_b figures show that due to presence of compensator the active and reactive powers are positive. Although active power is always positive it appears as negative due to complex conjugate mathematical tool.

Fig. 30 I_a

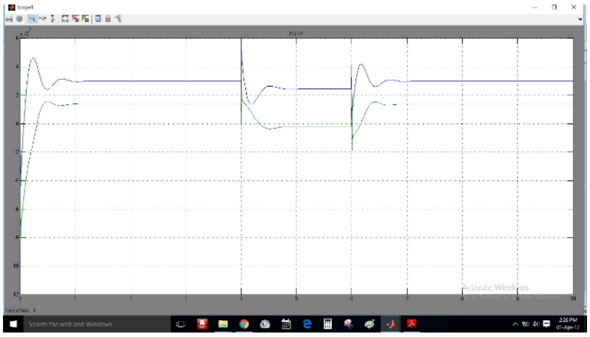

Fig. 30 I_b

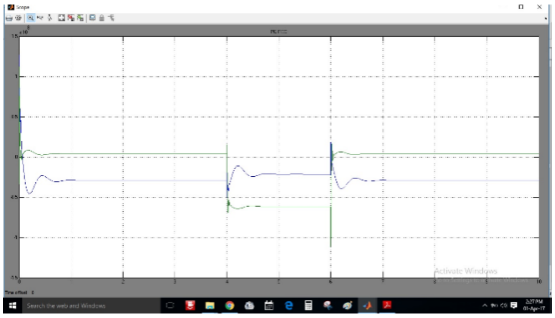

Fig. 30 II_a

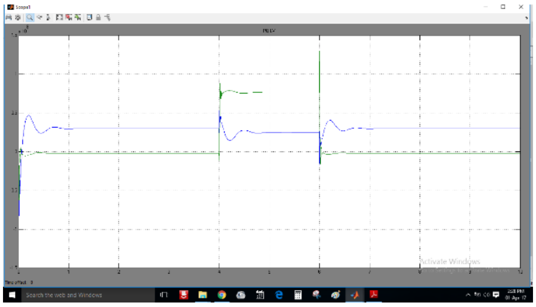

Fig. 30 II_b

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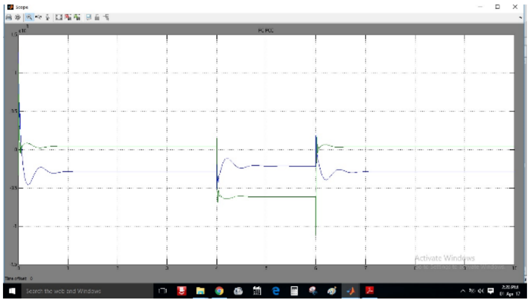


Fig. 30 III_a

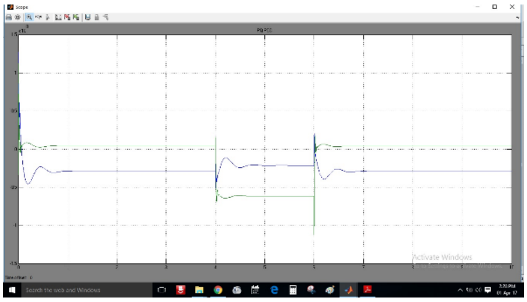
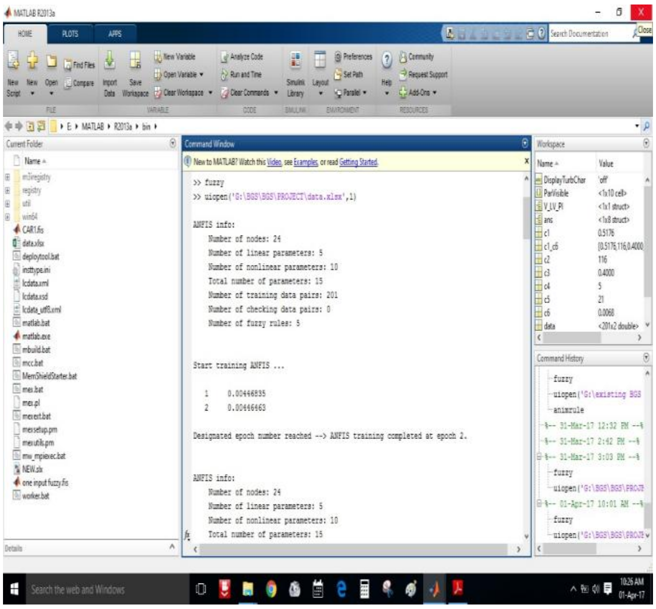


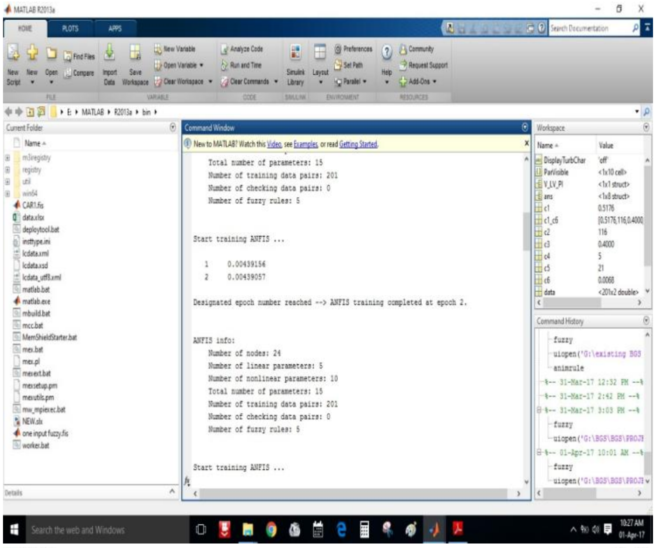
Fig. 30 III_b

Figures 30 : Comparison of active (green) and reactive power (blue) between (a) $B_{PCC}$ and (b) $B_{LV}$ amongst 3 models I, II, III.

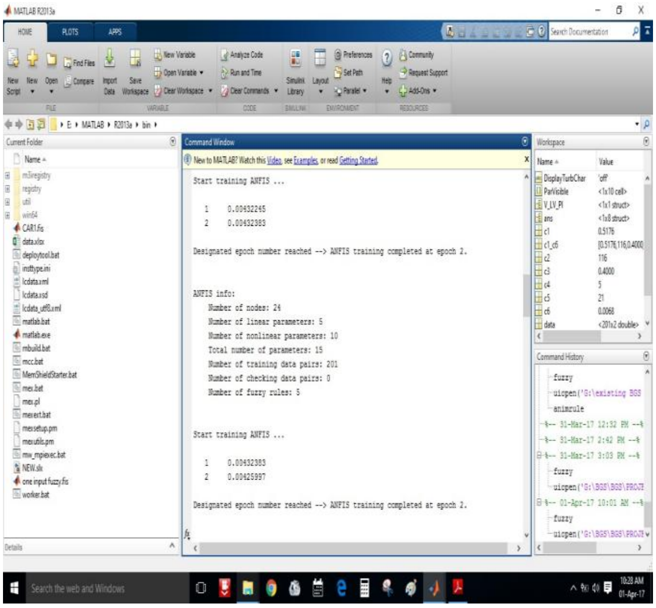
The figures in 31 show the series of steps required to do minimization of errors using trained data technique in Anfis way of solving a set of mechanical methods. The rule can be viewed in the Rule Viewer. Since the number of iterations (epochs) is 10, the final error is way lesser.



```
>> fuzzy
>> uiopen('G:\BGS\BGS\PROJECT\data.xlsx',1)

ANFIS info:
    Number of nodes: 24
    Number of linear parameters: 5
    Number of nonlinear parameters: 10
    Total number of parameters: 15
    Number of training data pairs: 201
    Number of checking data pairs: 0
    Number of fuzzy rules: 5


Start training ANFIS ...

  1      0.00446835
  2      0.00446463

Designated epoch number reached --> ANFIS training completed at epoch 2.


ANFIS info:
    Number of nodes: 24
    Number of linear parameters: 5
    Number of nonlinear parameters: 10
    Total number of parameters: 15
```



```
    Total number of parameters: 15
    Number of training data pairs: 201
    Number of checking data pairs: 0
    Number of fuzzy rules: 5


Start training ANFIS ...

  1      0.00439156
  2      0.00439057

Designated epoch number reached --> ANFIS training completed at epoch 2.


ANFIS info:
    Number of nodes: 24
    Number of linear parameters: 5
    Number of nonlinear parameters: 10
    Total number of parameters: 15
    Number of training data pairs: 201
    Number of checking data pairs: 0
    Number of fuzzy rules: 5


Start training ANFIS ...
```



```
Start training ANFIS ...

  1      0.00432245
  2      0.00432383

Designated epoch number reached --> ANFIS training completed at epoch 2.


ANFIS info:
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    Number of linear parameters: 5
    Number of nonlinear parameters: 10
    Total number of parameters: 15
    Number of training data pairs: 201
    Number of checking data pairs: 0
    Number of fuzzy rules: 5


Start training ANFIS ...

  1      0.00432383
  2      0.00425997

Designated epoch number reached --> ANFIS training completed at epoch 2.
```

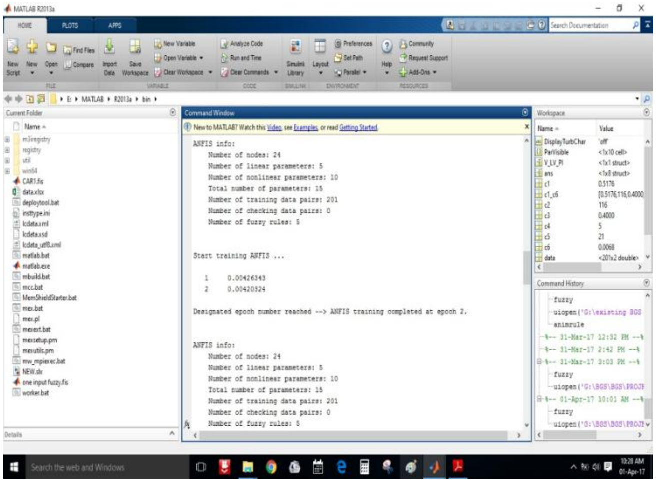

```
ANFIS info:
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    Number of linear parameters: 5
    Number of nonlinear parameters: 10
    Total number of parameters: 15
    Number of training data pairs: 201
    Number of checking data pairs: 0
    Number of fuzzy rules: 5


Start training ANFIS ...

  1      0.00426343
  2      0.00420324

Designated epoch number reached --> ANFIS training completed at epoch 2.


ANFIS info:
    Number of nodes: 24
    Number of linear parameters: 5
    Number of nonlinear parameters: 10
    Total number of parameters: 15
    Number of training data pairs: 201
    Number of checking data pairs: 0
    Number of fuzzy rules: 5
```
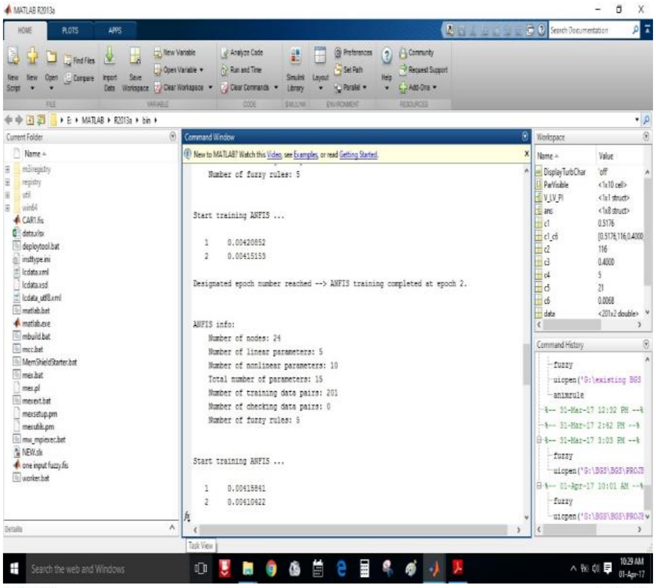
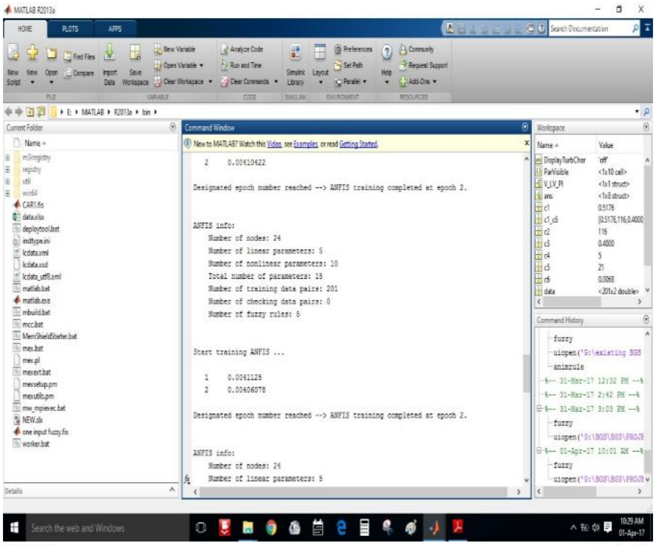
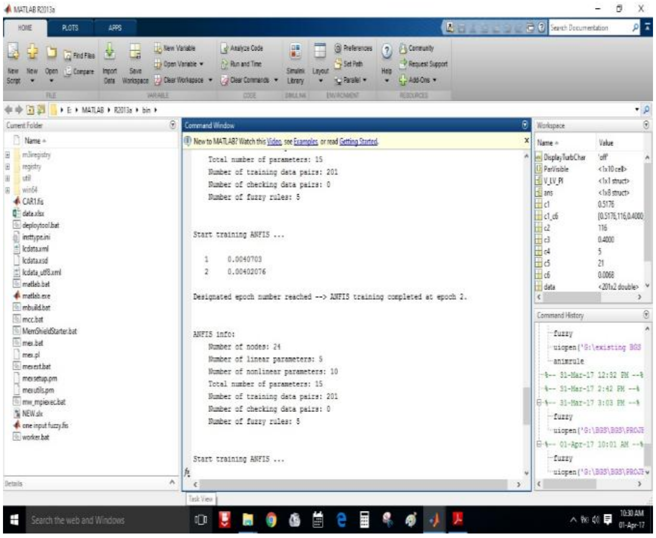



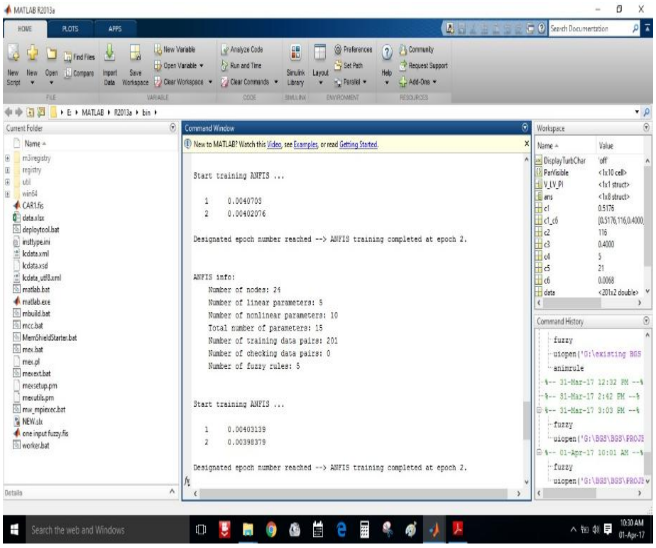
```
    Number of fuzzy rules: 5


Start training ANFIS ...

   1      0.00420852
   2      0.00415153

Designated epoch number reached --> ANFIS training completed at epoch 2.


ANFIS info:
    Number of nodes: 24
    Number of linear parameters: 5
    Number of nonlinear parameters: 10
    Total number of parameters: 15
    Number of training data pairs: 201
    Number of checking data pairs: 0
    Number of fuzzy rules: 5


Start training ANFIS ...

   1      0.00415841
   2      0.00410422
```



```
   2      0.00410422

Designated epoch number reached --> ANFIS training completed at epoch 2.


ANFIS info:
    Number of nodes: 24
    Number of linear parameters: 5
    Number of nonlinear parameters: 10
    Total number of parameters: 15
    Number of training data pairs: 201
    Number of checking data pairs: 0
    Number of fuzzy rules: 5


Start training ANFIS ...

   1      0.0041125
   2      0.00406078

Designated epoch number reached --> ANFIS training completed at epoch 2.


ANFIS info:
    Number of nodes: 24
    Number of linear parameters: 5
```



```
    Total number of parameters: 15
    Number of training data pairs: 201
    Number of checking data pairs: 0
    Number of fuzzy rules: 5


Start training ANFIS ...

   1      0.0040703
   2      0.00402076

Designated epoch number reached --> ANFIS training completed at epoch 2.


ANFIS info:
    Number of nodes: 24
    Number of linear parameters: 5
    Number of nonlinear parameters: 10
    Total number of parameters: 15
    Number of training data pairs: 201
    Number of checking data pairs: 0
    Number of fuzzy rules: 5


Start training ANFIS ...
```



```
Start training ANFIS ...

   1      0.0040703
   2      0.00402076

Designated epoch number reached --> ANFIS training completed at epoch 2.


ANFIS info:
    Number of nodes: 24
    Number of linear parameters: 5
    Number of nonlinear parameters: 10
    Total number of parameters: 15
    Number of training data pairs: 201
    Number of checking data pairs: 0
    Number of fuzzy rules: 5


Start training ANFIS ...

   1      0.00403139
   2      0.00398379

Designated epoch number reached --> ANFIS training completed at epoch 2.
```

Fig. 31 Minimization of errors using Anfis

It is clearly seen after all the iterations that the error due to PI controller of the StatCom controller is **0.00446835** and after all the epochs of Anfis the error is minimized to **0.00398379.**

Hence our aim of mimization of PI controller error by incorporating Anfis is achieved.

## CONCLUSION

The proposed model simulated using MATLAB Simulink analyzes how a StatCom controller structure does voltage control during unsymmetrical grid fault at a FSIG installed wind farm. The compensation of both positive and negative sequence components of voltage takes independently by the StatCom controller structure. The positive-sequence voltage compensation is given the highest priority. This project achieves its aim of coordinating between both the components of voltage. Hence it also studies the effect of this coordination and compensation upon wind turbine behavior. The compensation of positive sequence component of voltage gives the windfarm enhanced stability of voltage. The compensation of negative sequence component of voltage reduces torque ripple and thereby increases the lifespan of the generator. If after the compensation of positive sequence component of voltage there is still some current capability remaining with StatCom then it is used to do compensation of negative sequence component of voltage and thereby achieve desired results. Further Anfis incorporation enhances the operability and reduces error of the PI controller.

## Advantages of the Project:

- Enhanced stability of voltage
- Reduction in torque ripples
- The generator drive train's lifespan increases

## Future Enhancement:

- Reduce the complexity of StatCom controller structure
- Better programming of fuzzy logic controller
- To modify StatCom controller structure such that both the components of voltage can be compensated at a single time.
- To modify the StatCom controller structure such that the torque transients too can be smoothened.

## Applications:

- In grid- integrated renewable energy systems.

## REFERENCES

[1] C.Wessels, N. Hoffman, M.Molinas, F.W. Fuchs, "StatCom Control at Wind Farms With Fixed-Speed Induction Generators Under Asymmetrical Grid Faults," IEEE Trans. Ind. Electron., vol. 60, no. 7, pp. 2864-2872, Jul. 2013.

[2] M. Liserre, R. Cardenas, M. Molinas, and J. Rodriguez, "Overview of multi-MW wind turbines and wind parks," IEEE Trans. Ind. Electron., vol. 58, no. 4, pp. 1081–1095, Apr. 2011.

[3] C. Hochgraf and R. Lasseter, "STATCOM controls for operation with unbalanced voltages," IEEE Trans. Power Del., vol. 13, no. 2, pp. 538– 544, Apr. 1998

[4] E. Muljadi, D. Yildirim, T. Batan, and C. Butterfield, "Understanding the unbalanced-voltage problem in wind turbine generation," in Conf. Rec.34th IEEE IAS Annu. Meeting, 1999, vol. 2, pp. 1359–1365.

[5] D. Soto and T. Green, "A comparison of high-power converter topologies for the implementation of FACTS controllers," IEEE Trans. Ind.Electron., vol. 49, no. 5, pp. 1072–1080, Oct. 2002

[6] P. Rodriguez, R. Teodorescu, I. Candela, A. Timbus, M. Liserre, and F. Blaabjerg, "New positive-sequence voltage detector for grid synchronization of power converters under faulty grid conditions," in Proc. 37thIEEE PESC, Jun. 2006, pp. 1–7.

[7] C. Han, A. Huang, M. Baran, S. Bhattacharya, W. Litzenberger, Anderson, A. Johnson, and A.-A. Edris, "Statcom impact study on the integration of a large wind farm into a weak loop power system," IEEETrans. Energy Convers., vol. 23, no. 1, pp. 226–233, Mar. 2008.

[8] L. Xu, L. Yao, and C. Sasse, "Comparison of using SVC and statcom for wind farm integration," in Proc. Int. PowerCon , Oct. 2006, pp. 1–7.

[9] M. Molinas, J. A. Suul, and T. Undeland, "Low voltage ride through of wind farms with cage generators: STATCOM versus SVC," IEEE Trans.Power Electron., vol. 23, no. 3, pp. 1104–1117, May 2008.

[10] M. Molinas, J. Suul, and T. Undeland, "Extending the life of gear box in wind generators by smoothing transient torque with STATCOM," IEEETrans. Ind. Electron., vol. 57, no. 2, pp. 476–484, Feb. 2010.

[11] M. Tsili and S. Papathanassiou, "A review of grid code technical requirements for wind farms," IET Renewable Power Genera., vol. 3, no. 3, pp. 308–332, Sep. 2009.

[12] J. Suul, M. Molinas, and T. Undeland, "STATCOM-based indirect torque control of induction machines during voltage recovery after grid faults," IEEE Trans. Power Electron., vol. 25, no. 5, pp. 1240–1250, May 2010.

[13] M. Ali and B. Wu, “Comparison of stabilization methods for fixed speed wind generator systems,” IEEE Trans. Power Del., vol. 25, no. 1, pp. 323–331, Jan. 2010.

[14] P. Rodriguez, A. Luna, G. Medeiros, R. Tedorescu, and F. Blaabjerg, “Control of statcom in wind power plants based on induction generators during asymmetrical grid faults,” in Proc. IPEC, Jun. 2010, pp. 2066–2073.

[15] P. Rodriguez, G. Medeiros, A. Luna, M. Cavalcanti, and R. Teodorescu, “Safe current injection strategies for a statcom under asymmetrical grid faults,” in Proc. IEEE ECCE, Sep. 2010, pp. 3929–3935.

[16] P. Rodriguez, G. Medeiros, A. Luna, M. Cavalcanti, and R. Teodorescu, “Safe current injection strategies for a statcom under asymmetrical grid faults,” in Proc. IEEE ECCE, Sep. 2010, pp. 3929–3935.

[17] C. Wessels, F. Fuchs, and M. Molinas, “Voltage control of a statcom at a fixed speed wind farm under unbalanced grid faults,” in Proc. 37th IEEEIECON, Nov. 2011, pp. 979–984.