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Analysis of Neuro-Fuzzy-Based STATCOM and SSSC

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ABSTRACT—

When a wind farm is integrated into the power system, it encounters stability issues. To maintain air gap flux, fixed-speed induction generators require reactive power. Static Synchronous Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC) reactive power equipment can be used to recover induction generators from severe system disturbances and stabilize grid-connected wind generators. These devices are capable of absorbing or injecting reactive power. A nonlinear controller is a neuro-fuzzy controller (NFC). Neuro-Fuzzy controlled STATCOM and SSSC can be used to stabilize grid-connected wind turbines.

Keywords— wind farm (WF), grid, Induction Generator (IG), STATCOM, SSSC, reactive power compensation, Neuro-fuzzy controller (NFC), various types of faults.

1. Introduction:

A wind farm (WF) is made up of several wind turbine-generating systems that work together. Because of their simple, rugged, and maintenance-free construction, induction generators (IG) are widely used as wind turbines. IGs are directly connected to the power grid. IGs need reactive power to produce active power in order to sustain air gap flux.

The grid provides this reactive power. When disturbances such as faults occur, IGs' reactive power consumption increases. If the grid is unable to meet the reactive power requirements of IGs, wind turbines trip. This has an impact on the voltage profile of the bus to which WF is connected, resulting in grid instability. As a result, whenever a grid disturbance occurs, reactive power compensation is required to maintain grid stability.

Popular flexible AC transmission systems (FACTS) tools like Static Synchronous Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC) are particularly helpful for delivering reactive power and supporting the bus voltage of a WF at the same time. By regulating the amount of reactive power injected into or absorbed from the power supply, both adjust the voltage at terminals. Reactive power is produced when the system voltage is low (capacitive). They take in reactive power when the system voltage is high (inductive).

Neuro-fuzzy(NF) control can effectively deal with power system uncertainties. Neuro-fuzzy is the combination of neural network and fuzzy logic in the case of STATCOM, the conventional PI controller is used to generate the reference current Iqref, and in the case of SSSC, vq_conv. The PI controller necessitates the use of precise linear mathematical models. It is extremely difficult to obtain parameter variation in the presence of nonlinearity and load disturbance, and its performance is subpar. The benefit of neuro-fuzzy controllers (NFC) over traditional controllers is that they do not require an accurate mathematical model. NFC is capable of working with imprecise inputs. It handles nonlinearity and is more robust than a traditional PI controller. NFC mimics human decision-making and can often be used more successfully in complex systems than traditional control techniques. This paper compares neuro-fuzzy controlled STATCOM and SSSC for various types of faults.

2. STATCOM & SSSC Model

The static synchronous compensator (STATCOM) is a shunt controller, and the static synchronous series compensator (SSSC) is a series FACTS controller that uses voltage-sourced converter VSC technology. A VSC produces a synchronous voltage with a fixed fundamental frequency and variable magnitude and phase angle. The output vq_conv of the Vq voltage regulator block is fed to the PWM modulator, which controls the pulses of the SSSC's VSC. The output Iqref of the AC voltage regulator block is given to the current regulator and then to the PWM modulator, which controls the pulses of the STATCOM's VSC, the schematic diagram of the control system of a STATCOM and SSSC is shown in Fig 1 and Fig 2.

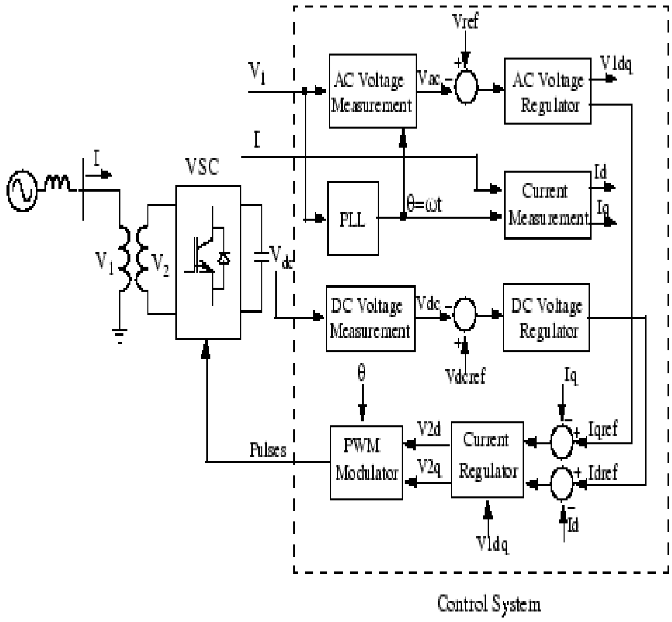


Fig 1. Schematic Diagram of the control system of a STATCOM

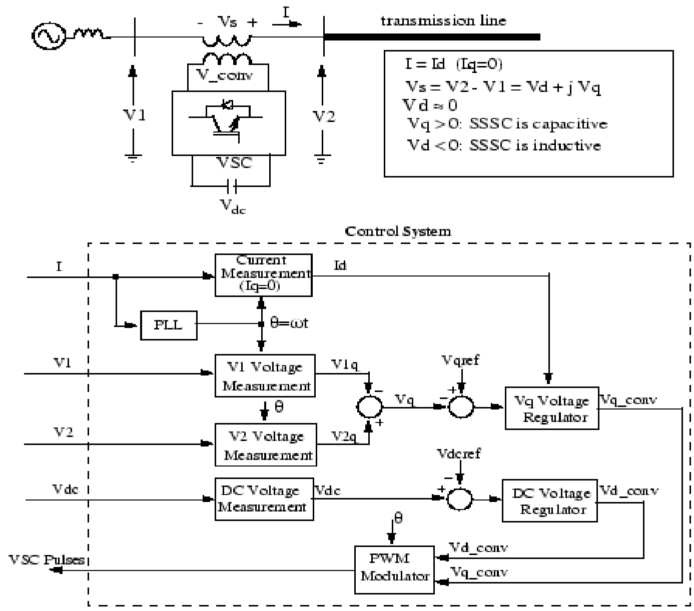


Fig 2. Schematic Diagram of the control system of an SSSC.

3. Modelling of neuro fuzzy controller

Neuro-fuzzy controller (NFC) is a combination of a neural network (NN) and a fuzzy system (FS). Neuro-fuzzy systems are well-known for their ability to Combine the benefits of FS and NN. The outputs of NN and FS are combined in this paper to modify the overall output.

The FLC has two inputs: error voltage (ev) and change in error voltage (cev). In the case of STATCOM, iqref is the controller output, and vq_conv is the output of SSSC. The FLC output and inputs are scaled for convenience using the coefficients kIqref, kvq_conv, kcev, and kev. These scaling factors were chosen by trial and error in this paper as shown in Fig 3, the input fuzzy sets use triangular membership functions with overlap. The language Variables are denoted by N (Negative), Z (Zero), and P (Positive) (Positive).

The following IF-THEN rules are used to indicate the fuzzy mapping of the input variables to the output:

IF(ev=N) and (cev=N) THEN (output=P)

IF(ev=N) and (cev=Z) THEN (output=P)

IF(ev=N) and (cev=P) THEN (output=Z)

IF(ev=Z) and (cev=N) THEN (output=P)

IF(ev=Z) and (cev=Z) THEN (output=Z)

IF(ev=Z) and (cev=P) THEN (output=N)

IF(ev=P) and (cev=N) THEN (output=Z)

IF(ev=P) and (cev=Z) THEN (output=N)

IF(ev=P) and (cev=P) THEN (output=N)

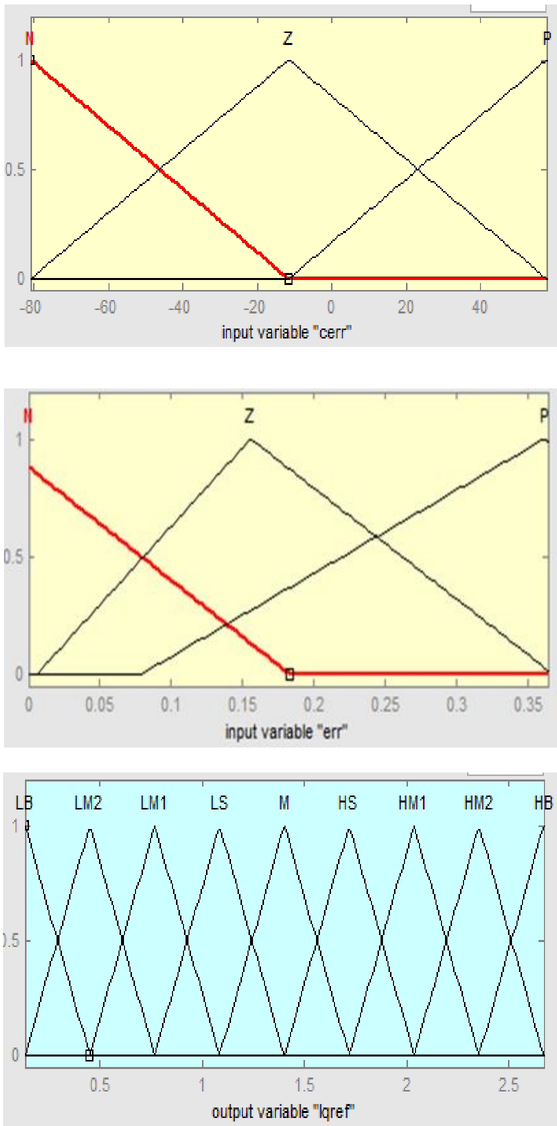


Fig 3. Rule base and Membership function of the neuro-fuzzy controller.

STATCOM output is Iqref, while SSSC output is vq_conv. The designed neural network is a feed-forward two-layer network with 20 neurons. In order to train the network, the Leaven Berg Marquardt approach is employed. Fig 4 and 5 depict the design of a neuro-fuzzy controller. The NFC is connected to the AC voltage regulator of the STATCOM block and the injected voltage regulator of the SSSC block, as shown in Fig.

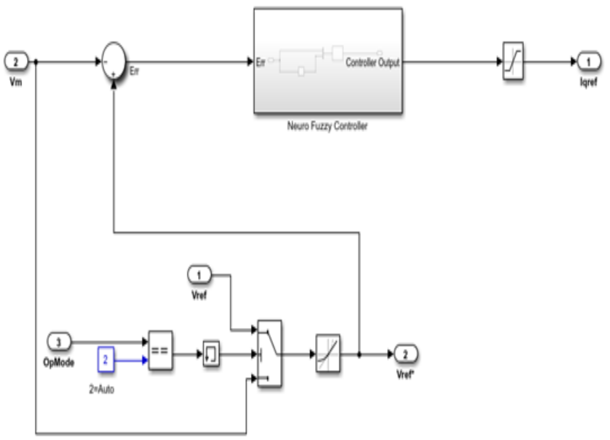


Fig 4. NFC Connected to AC voltage regulator of STATCOM

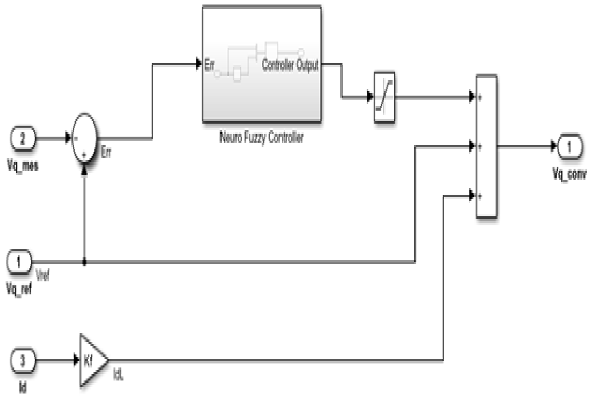


Fig 5. NFC connected in injected voltage regulator of SSSC

4. Model of test system

The wind farm under consideration in this paper has three 3 MW turbines. As a result, the wind farm has a capacity of 9 MW. Mentioned A 120/25 kV transformer and a 203 25 kV, 2-lined distribution line with a 25 km length and a 120/25 kV transformer connect the units to the grid. In this model, squirrel cage induction generators are used, and stator windings are directly connected to

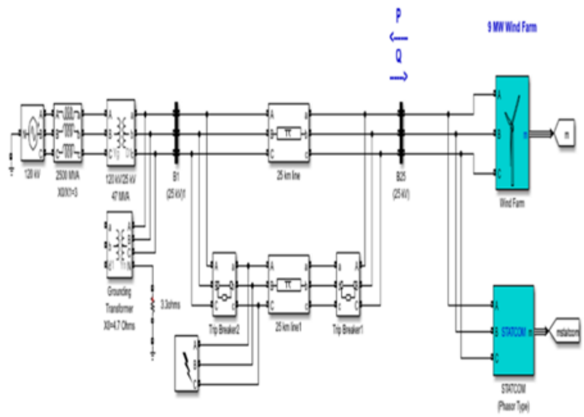


Fig 6. Test system model with STATCOM.

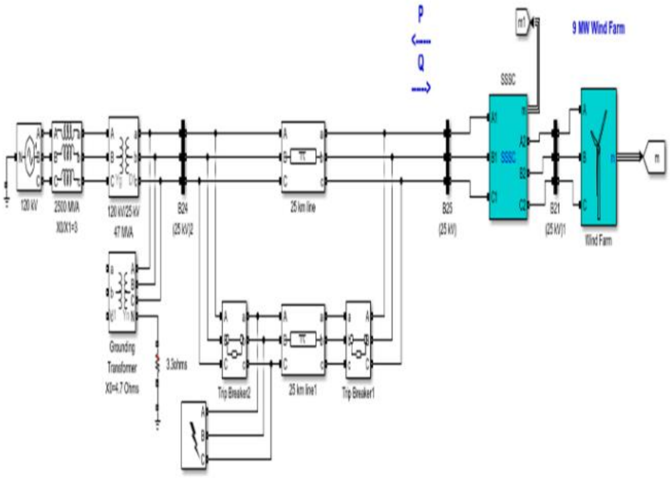


Fig 7. Test system model with SSSC.

the grid, with a capacitor bank used at the junction point to compensate for a portion of the required reactive power. Figures 6 and 7 show simulated system models for STATCOM and SSSC, respectively. This grid is used to investigate and assess machine and wind farm stability.

5. Analysis of simulations

Several tests were run to compare the performance of the neuro-fuzzy controlled STATCOM & SSSC with neuro-fuzzy control.

Case Study-1: An LLLG fault occurs 25 kilometers on a transmission line near a circuit breaker (C.B) at 15 seconds and is cleared after 200 milliseconds or 15.2 seconds. The system's settling time has decreased, making it relatively stable. Below figures depict neuro fuzzy. STATCOM has a shorter settling time than neuro fuzzy SSSC.

Case Study 2: An LLG fault occurs on a 25-kilometer transmission line near the CB at 15 seconds and is cleared after 200 milliseconds or 15.2 seconds.

Case Study 3: An LL fault occurs at 15 seconds on a 25-kilometer transmission line near the CB and is cleared after 200 milliseconds, i.e. the fault is cleared at 15.2 seconds.

Case Study 4: An LG fault occurs at 15 seconds on a 25-kilometer transmission line near CB and is cleared after 200 milliseconds. At 15.2 seconds, the fault is cleared.

Case Study 5: A LLL fault occurs at 15 seconds on a 25-kilometer transmission line near the CB and is cleared after 200 milliseconds. i.e. fault removed at 15.2sec.

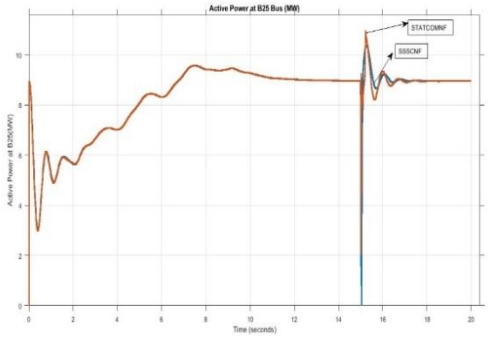
Case Study 6: A LLL fault occurs at 15 seconds on a 25-kilometer transmission line near the CB and is cleared after 200 milliseconds. At 15.2 seconds, the fault was cleared.

6. Conclusion

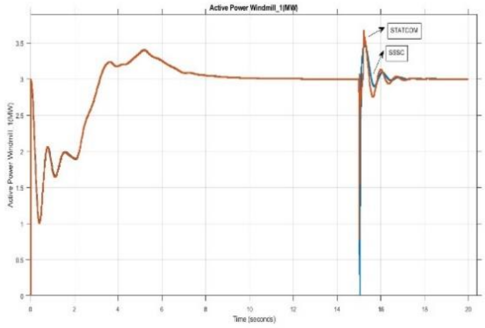
It is made abundantly evident that STATCOM fitted with a neural fuzzy controller performs better and operates faster. SSSC paired with a neuro-fuzzy controller provides a faster response. The neuro-fuzzy STATCOM response is superior to the neuro-fuzzy SSSC response when the system is used with different cases in this paper. Using neuro-fuzzy STATCOM compared to neuro-fuzzy SSSC, the system is more stable. As a result, it can be stated that it is preferable to connect STATCOM with a Neuro-fuzzy controller in the instances and systems under consideration because it may boost stability and improve grid-connected wind generator performance better than SSSC.

CASE 1: LLLG FAULT

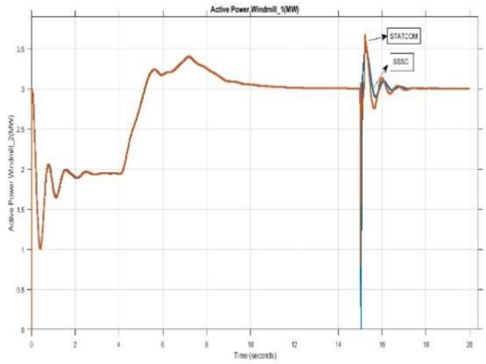
Active power at B25 Bus



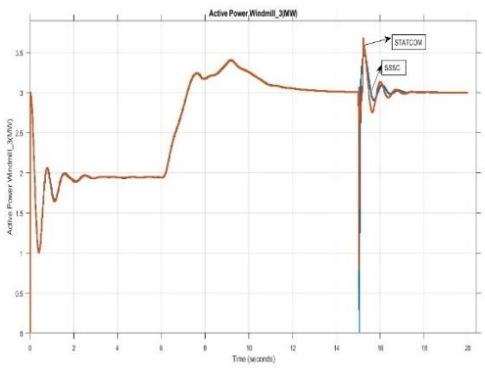
Active power at Windmill 1



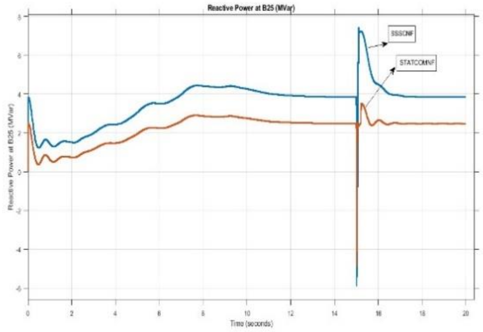
Active power at Windmill 2



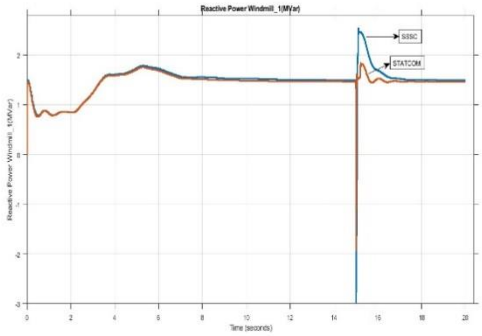
Active power at Windmill 3



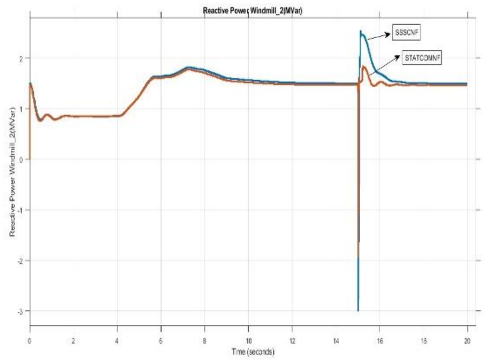
Reactive power at B25



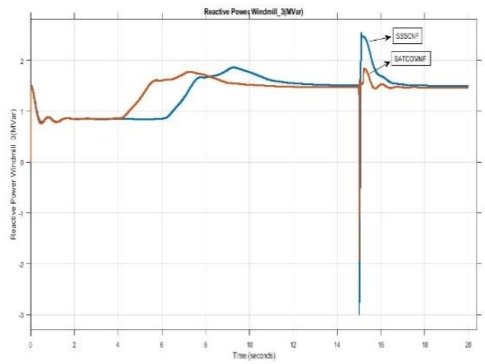
Reactive power at Windmill 1



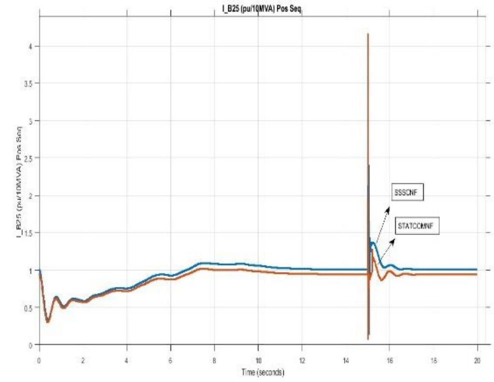
Reactive power at Windmill 2



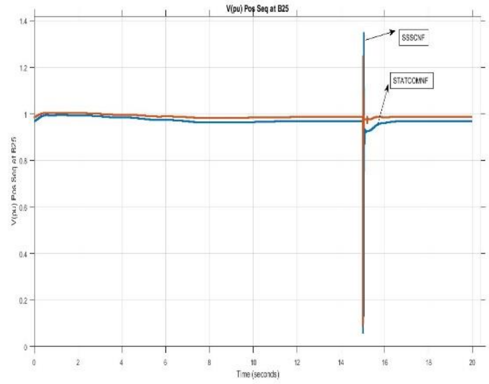
Reactive power at Windmill 3



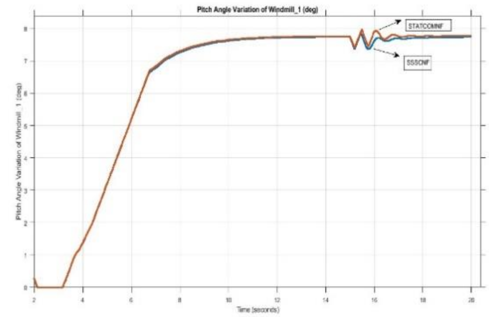
Current at B25 Bus



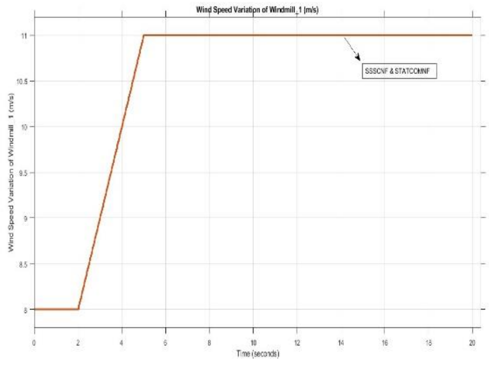
The voltage at B25 Bus



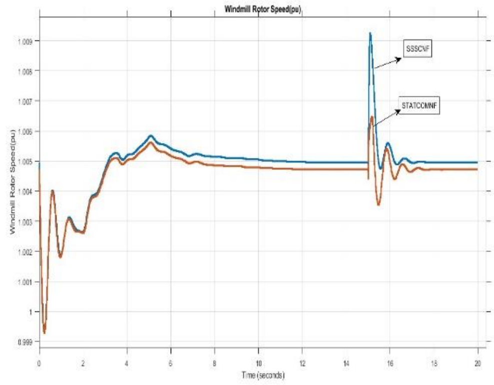
Pitch angle variation of a windmill



Wind speed variation of a windmill

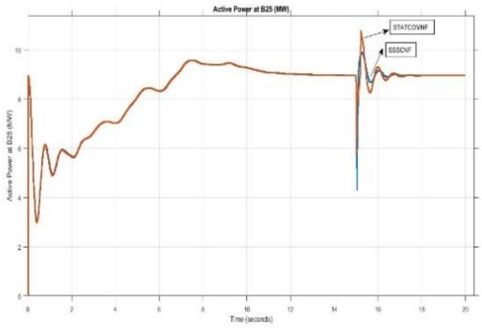


Windmill rotor speed

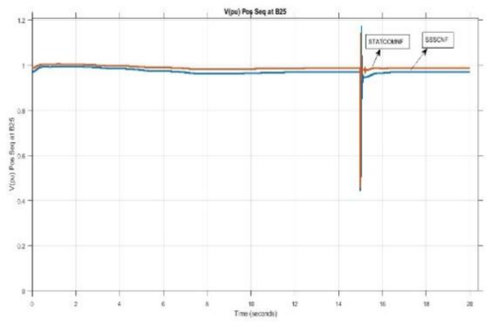


CASE 2: LLG FAULT

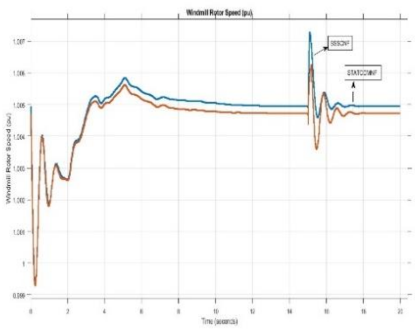
Active power at B25 Bus



The voltage at the B25 bus

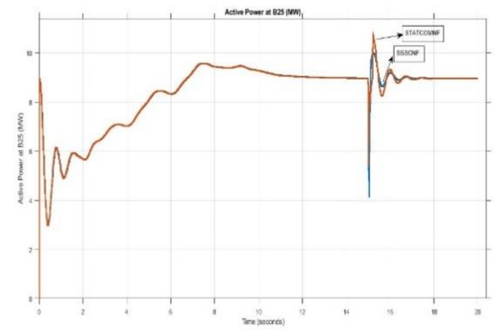


Windmill rotor speed

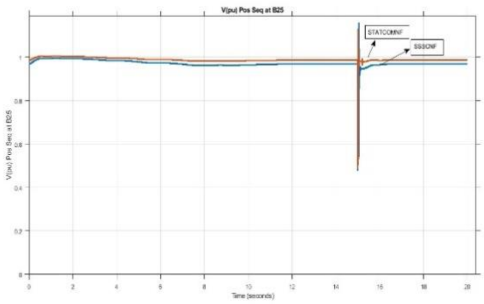


CASE 3: LL FAULT

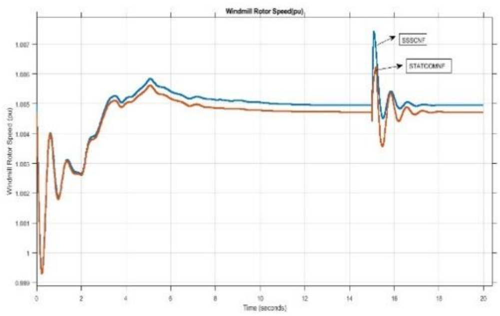
Active power at B25 Bus



The voltage at B25 Bus

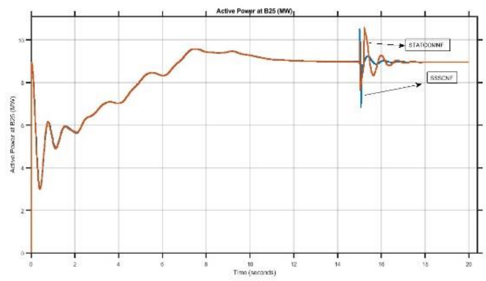


Windmill rotor speed

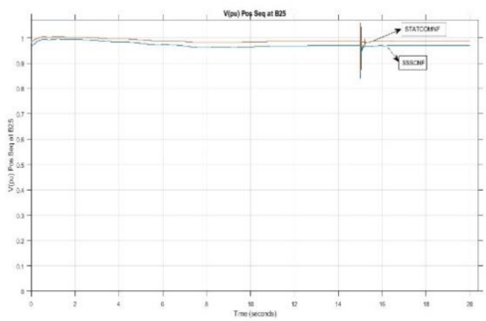


CASE 4: LG FAULT

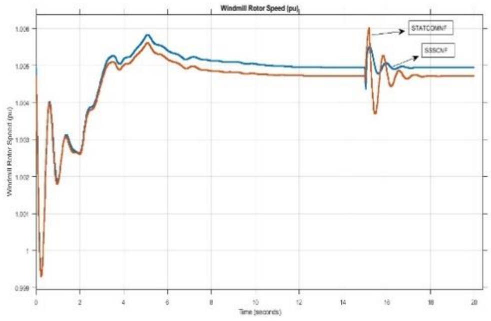
Active power at B25 Bus



The voltage at B25 Bus

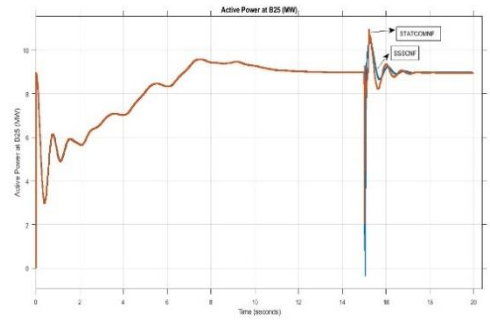


Windmill rotor speed

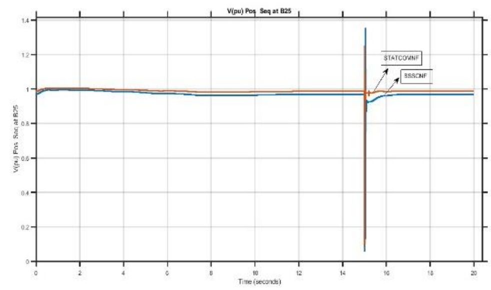


CASE 5: LLL FAULT

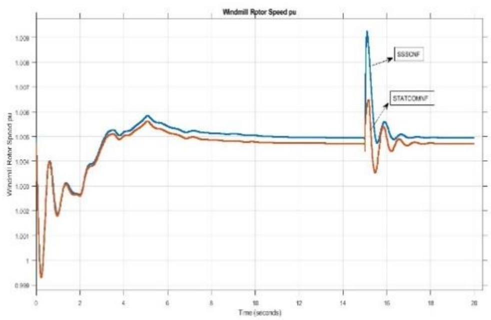
Active power at B25 Bus



The voltage at B25 Bus



Windmill rotor speed



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