10431 Session 2022

Study Committee SC-A1 | PS 1 – GENERATION MIX OF THE FUTURE

CASE STUDY FOR SYNCHRONOUS CONDENSER IMPLEMENTATION

A NOVEL SOLUTION FOR GRID STABILITY AND SHORT CIRCUIT POWER IN ERA OF RENEWABLES

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SUMMARY

In order to achieve Green House Emission targets and to reduce dependency on fossil fuel-based generation, most of the countries around the world are planning to increase the generation from renewable sources. Government of India (GoI) has set a target of achieving 175 GW of renewable generation by 2022 and 500 GW by 2030. The increasing penetration of renewable energy poses many challenges to the stability and reliability of the power system. The paper brings out the challenging aspects of requirement of short circuit power, inertia and dynamic reactive power in the changing grid scenario and available technologies to deal with these challenges.

Simulation studies carried out for understanding the effect of renewable integration on short circuit power, inertia and reactive power are included in the paper. Further, case study of a location with huge planned renewable integration and few conventional generators in near vicinity is also discussed. The generation mix in the case study represents the possible situation of Indian grid in near future. Short Circuit Ratio (SCR) at various nodes/point of interconnection after integration of renewable energy generators is studied. The response of different technologies available (SVC, STATCOM and synchronous condensers) during the transient conditions have been presented.

Synchronous condensers are the most optimized and strongest technical solution to deal with problems of low inertia, short circuit power and requirement of reactive power reserves. The synchronous condensers can be installed at strategic locations along a transmission network such as near renewable generating stations, HVDC link etc. The location and specifications of synchronous condensers shall be finalized based on the system studies which will provide details about the type of ancillary services required at a particular location.

Synchronous Condenser based augmentation of power networks with installation at strategic locations can make the system performance at par with conventional power generation technologies, where active power is being generated from wind farms or solar parks and other requirements like ‘system inertia, short circuit withstand capability, dynamic voltage support, and synchronizing and damping torque’ are met by the synchronous condenser.

KEYWORDS

Synchronous condenser, synchronous inertia, renewable integration, short circuit power, simulation studies

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1. INTRODUCTION

With the increasing penetration of renewables in the grid, new HVDC connections and retiring thermal plants, there is a challenge for grid stability due to lack of inertia and short circuit power. Short circuit power, inertia and reactive power compensation have inherently been provided by the conventional generators and hence grid stability has never been an issue in the pre-renewable era. The renewable generators which mostly consist of solar and wind are integrated to the power system with the use of power electronic devices. The renewable generators connected through these power electronic devices pose challenges to the power system as they cannot provide inertia, have limitations of providing short circuit power, reactive power and introduce harmonics in the power system. Inertia is required in the system for frequency control and short circuit power and reactive power is required for voltage support and voltage regulation.

Presently, the total installed capacity of India is around 400 GW. The capacity from fossil fuel-based sources (coal, lignite, gas, diesel etc.) is around 60%, hydro is around 12% and renewable is around 26%. India is progressing in renewable growth and taking steps towards reducing carbon emissions to achieve the commitment of producing energy from non-fossil fuel-based sources. There has been continuous addition of renewable energy capacity in the Indian transmission network over the past few years and now we have come to a point where we have started withdrawing conventional energy from grid. The increase in renewable energy in grid along with retirement of conventional energy-based plants shall lead to considerable decrease in inertia, short circuit strength, dynamic reactive power reserves which are essential for overall stability and reliability of the power system.

2. CHANGING GRID SCENARIO

Government of India (GoI) has set a target of achieving 175 GW of renewable generation by 2022 and 500 GW of renewable energy by 2030. The generation mix in 2030 is going to change with fossil fuels contributing approximately 36% (compared to 60.4% in 2021) and renewables contributing 52% (compared to 25.9% in 2021). A comparison of generation mix in 2021 and likely generation mix in 2030 in given in Figure-1.

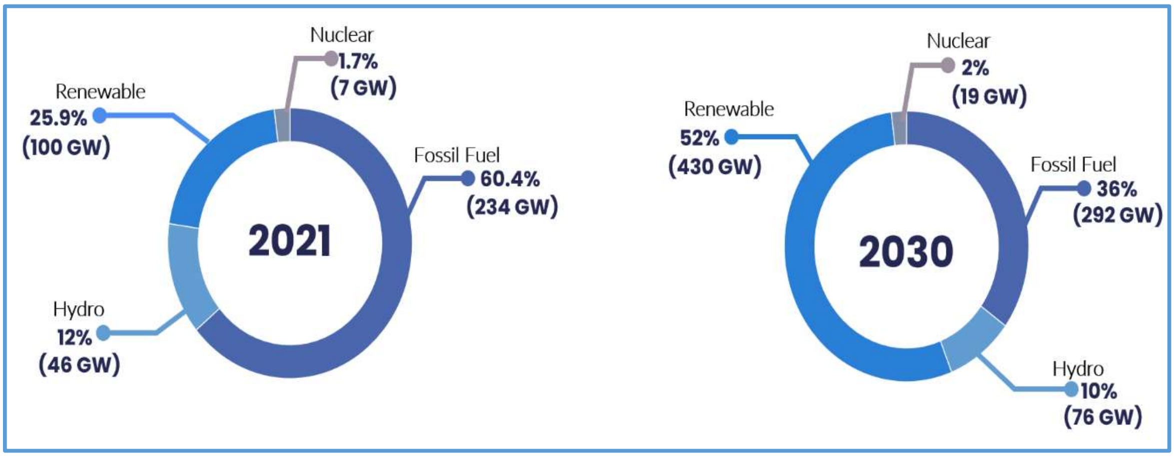


Figure-1-Generation Mix Scenario in India (2021 and 2030)

3. GRID STABILITY ISSUES WITH RENEWABLE INTEGRATION

The availability of key elements for grid stability i.e. inertia, short circuit power and dynamic reactive power shall start diminishing due to combined effect of addition of renewable energy and withdrawal of conventional energy sources from the grid. Therefore, in changing generation mix scenario of future grid, additional systems may have to be installed for the ancillary services inherently provided by the conventional generators.

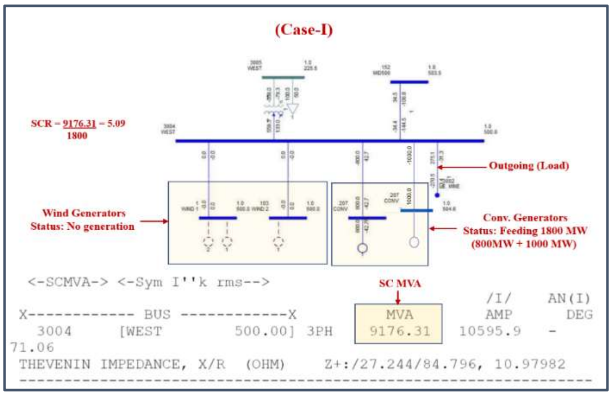
A simulation has been carried out on a sample network to understand the effect of renewable integration on SCR. Sample network configuration is shown in **Figure-2** below. Sample network was modelled in PSSE where system bus is connected to 1800 MW of conventional generation and 800 MW of renewable generation (in form of wind generation). Load flow and dynamic simulation studies have been carried out to understand the effect of the addition of renewable sources and withdrawal of conventional sources on Short circuit power, ROCOF (inertia) and voltage stability (dynamic reactive power levels).

3A. Short Circuit Power

It is the power required to maintain the voltage level in case of a fault. Short circuit power reflects the system strength. SCR of a bus is defined as the ratio of SC MVA to the MW rating connected at that bus. With the additional of renewable energy and withdrawal of conventional energy from grid, there shall be significant decrease in short circuit power which needs to be compensated. The reason for decrease in short circuit power is due to the fact that renewable generators are limited by rating of the electronic components. The short circuit power provided by renewable generators is not enough to detect the fault and results in continuous feeding of the fault. The SCR (Short Circuit Ratio) of a node represents the ability of the bus to withstand the voltage fluctuations in response to the fault. Higher is the SCR, higher is the strength of the system. Considering the changing grid scenario, synchronous condensers can be the best solution for increasing the short circuit power capability of the network.

Simulations of the following cases have been carried out on sample network described above:

- **Case-I:** All conventional generation connected in the bus (1800 MW) and no renewable generators connected **(Figure-2)**. **SCR calculated in this case is 5.09.**
- **Case-II:** Addition of 2 nos. wind generators (400 MW each) in Case-I **(Figure-3)**. **SCR calculated in this case is 3.63.**
- **Case-III:** Conventional generation of 800 MW is removed from case-II **(Figure-4)**. **SCR calculated in this case is 2.445.**
- **Case-IV:** All renewable generators and one synchronous condenser (400/-320 MVAR) **(Figure-5). SCR calculated in this case is 5.24.**



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                                                    /I/     AN(I)
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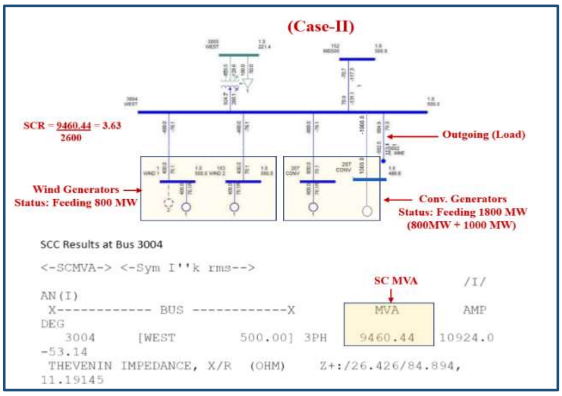
  3004      [WEST        500.00] 3PH   9176.31  10595.9   -
71.06
 THEVENIN IMPEDANCE, X/R  (OHM)    Z+:/27.244/84.796, 10.97982
 ------------------------------------------------------------------
```

Figure-2



SCC Results at Bus 3004

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DEG
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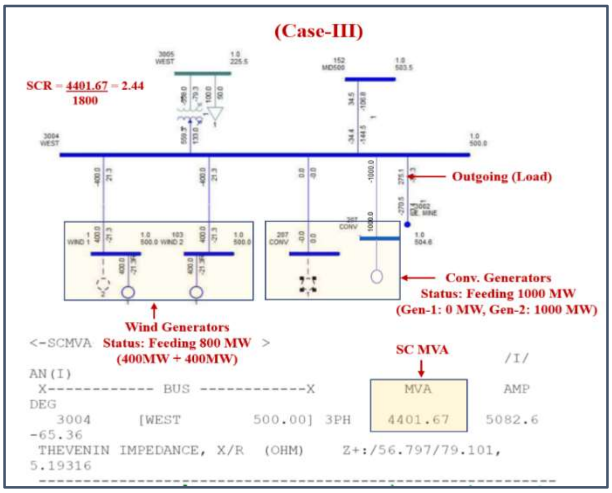
Figure-3



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AN(I)
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DEG
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5.19316
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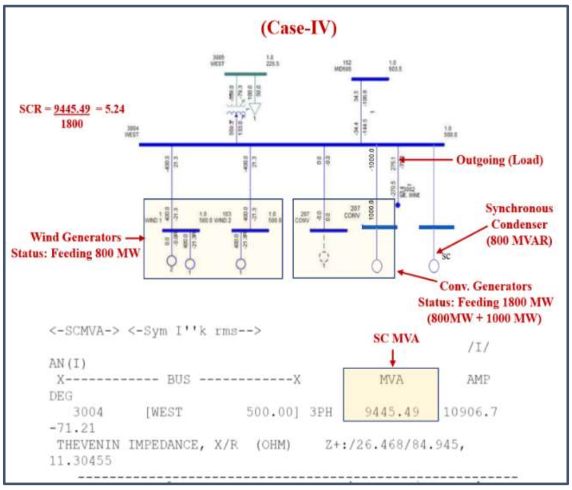
Figure-4



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                                                  /I/
AN(I)
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DEG
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-71.21
 THEVENIN IMPEDANCE, X/R  (OHM)    Z+:/26.468/84.945,
11.30455
   ------------------------------------------------------
```

Figure-5

3B. Inertia

One of the most important challenges of renewable integration is the provision of inertial stability provided by the conventional generators. The kinetic energy of the conventional generators acts like a shock absorber to keep the grid frequency in control during sudden supply-demand changes over very short periods. In the absence of inertia from the system, there may be frequent generator trippings during the load fluctuations and this may even lead to cascading outages in the system.

The renewable generators are connected to the grid using power electronic convertors/devices and hence they cannot provide the inertia for grid stability. As a result, the rate of change of frequency (RoCoF) becomes large with renewable integration. RoCoF indicates the robustness of a power system to withstand sudden imbalances. There a is a need to monitor inertia and figure out means to add inertia into the system at strategic locations.

For understanding the effect of the renewable sources on inertial stability, a simulation for RoCoF in case of faults has been carried out for the following cases on the sample network described earlier:

Case I: Only conventional generation of 800 MW connected in the bus **(Figure-6)**
Case II: Only wind generation of 800 MW connected in the bus **(Figure-6)**

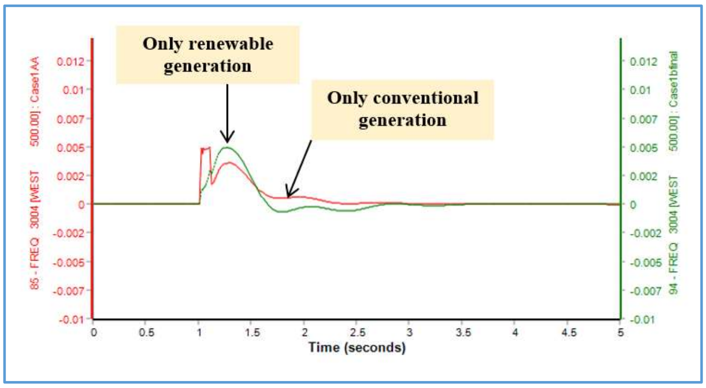


Figure-6

3C. Dynamic Reactive Power

Another issue which will crop up in the future grid generation mix shall be significant decrease in reactive power levels/reserves. During the transient fault conditions, low inertia wind turbines and inertia less solar generation may not be able to provide the required voltage support to the grid without proper reactive power support mechanisms. Also, long distance transmission corridors (between load centres and renewable generators) may become unstable during system contingencies/faults due to lack of reactive power. Therefore, it becomes important to identify locations where reactive power reserves shall be required after renewable integration to ensure a stable and reliable system.

For understanding the effect of the renewable sources on voltage stability(dynamic reactive power), a simulation for bus voltage restoration time in case of system faults has been carried out for the following cases on the sample network described earlier:

Case I: Only conventional generation of 800 MW connected in the bus **(Figure-7)**
Case II: Only wind generation of 800 MW connected in the bus **(Figure-7)**

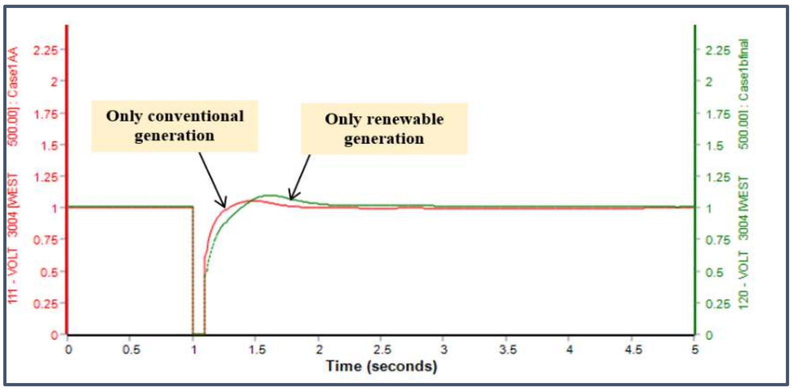


Figure-7

4. AVAILABLE TECHNOLOGIES FOR GRID STABILITY

The available technologies for grid stability can broadly be classified as:

- FACT devices i.e. Flexible AC Transmission System
- Rotating machines which include the conventional generators and synchronous condensers.

4A. FACT devices:

These are static power electronic devices installed in AC transmission system to increase the power transfer capability, improve the stability of the network etc. According to the connection mode in the Power System, the FACT devices can be classified as:

- Shunt Devices like SVC (Static VAR Compensator) and STATCOM (Static Synchronous Compensator)
- Series Connected Devices (Thyristor Controlled Series Capacitor, Thyristor Controlled Series Reactor)

4B. Synchronous condenser:

It is a conventional solution that has been used for many years for regulating reactive power before there were any power electronics compensation systems.

A synchronous condenser is a synchronous machine whose shaft is not attached to any driving equipment. A typical capability curve of synchronous condenser is given in Figure-8. Area highlighted in red indicates the operation zone of synchronous condenser.

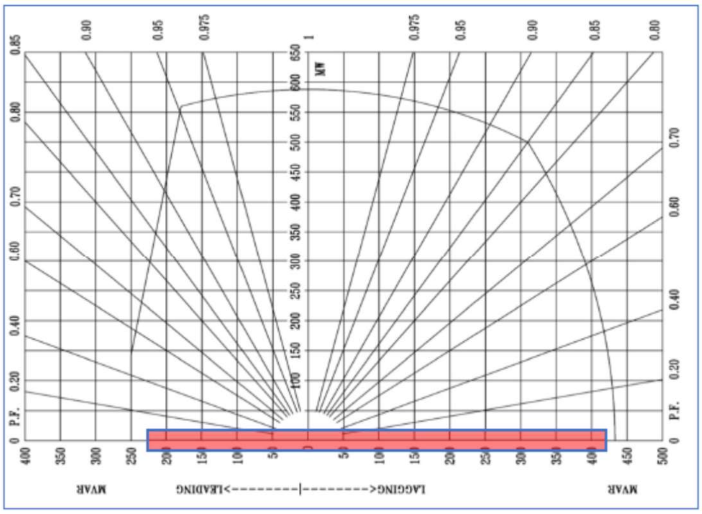


Figure-8

5. COMPARISON OF AVAILABLE TECHNOLOGIES

SVCs and STATCOMs cannot provide inertia and have a very limited capability to provide short circuit power which is essential for ensuring grid stability and reliability in renewable era.

Further, synchronous condenser-based augmentation of power networks shall have the following advantages over SVCs/STACOMs:

- **Provision of inertia, short circuit power, overload capability and low voltage ride through (LVRT)** in addition to dynamic reactive power
- **Low Cost of Installation**
- **No harmonics** in the Power System

5A. Comparison Based on the Support Provided

Support	Synchronous Condenser	STATCOM	SVC
Inertia (Frequency Stability)	YES	NO	NO
Dynamic Reactive Power Support	YES	YES	YES
Short Circuit Power	Very High	Very Limited	Very Limited
Overload Capacity	Very High 200% for 12 sec	No/expensive highly overrated components	No

5B. Comparison Based on the Technical Parameters:

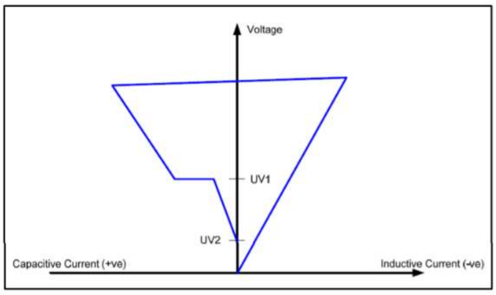
Technical Performance	Synchronous Condenser	STATCOM	SVC
Response time for frequency support	Instantaneous (Rotating Inertia)	No	No
Response time for voltage regulation	Medium (Sub-Transient behaviour of generator)	Fast (Use of power electronic components)	Medium
Full Load Losses	1.5%	1%	1%
CAPEX (for frequency support)	Low	No Frequency support	No Freq. support
CAPEX (for voltage regulation)	Medium	Medium	Low
OPEX	Low	Low	Low

5C. Comparison Based on other features

Other Features	Synchronous Condenser	STATCOM	SVC
Space Requirements	Compact	Medium	Large
Technology Readiness	Proven	Proven	Proven
Installation	Outdoor	Part outdoor/ part indoor	Part outdoor/ part indoor
Harmonics	No	Yes	Yes

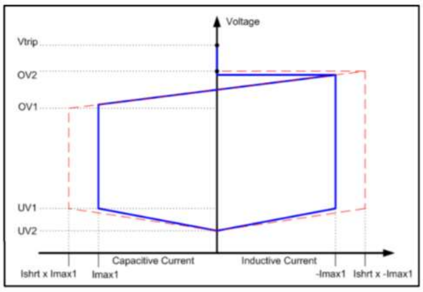
5D. Studies for Performance Comparison

The reactive power compensation provided by a STATCOM is more than SVC because at a low voltage limit, the reactive power drops off as the square of the voltage for the SVC but drops off linearly with the STATCOM. This makes the reactive power controllability of the STATCOM superior to that of the SVC, particularly during times of system distress. Typical VI characteristics of SVC and STATCOM are given in **Figure-9 and 10** respectively.



SVC

Figure-9



STATCOM

Figure-10

In case of fault in the network, maximum reactive output current of STATCOM will not be affected by the voltage magnitude (constant current characteristic). On the other hand, SVC's MVA output is proportional to the square of the voltage magnitude. Therefore, SVCs capacity to provide reactive power to the system decreases when it is needed the most. STATCOMs in comparison can inject maximum current at reduced voltage also. A simulation carried out to understand response of SVC and STATCOM during transient condition is given in **Figure-11.**

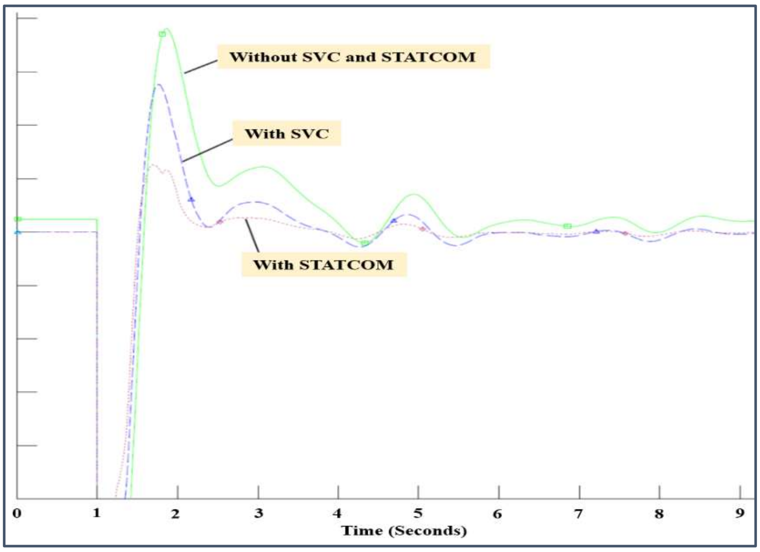


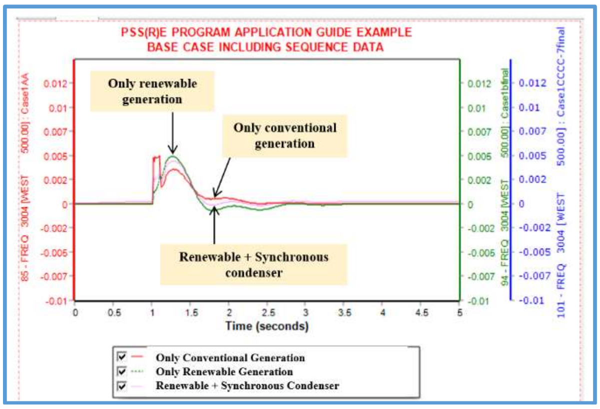
Figure-11

A simulation study for frequency regulation has been carried out on sample network described earlier (Figure-2) for understanding the effect of adding synchronous condenser in the network. The simulation study results are presented in **Figure-12**. Following cases have been considered for simulation studies during transient conditions:

- Only conventional generation (800 MW) connected in the bus
- Only renewable generation (800 MW) connected in the bus
- Renewable generation with synchronous condenser connected (250 MVAR)

Further, voltage response considering major outage (for better clarity) in the network is simulated in **Figure-13**. Following cases have been simulated:

- Only renewable generation (800 MW) in the sample network
- Renewable generation (800 MW) with STATCOM (250 MVAR) connected
- Renewable generation (800 MW) with synchronous condenser (250 MVAR)



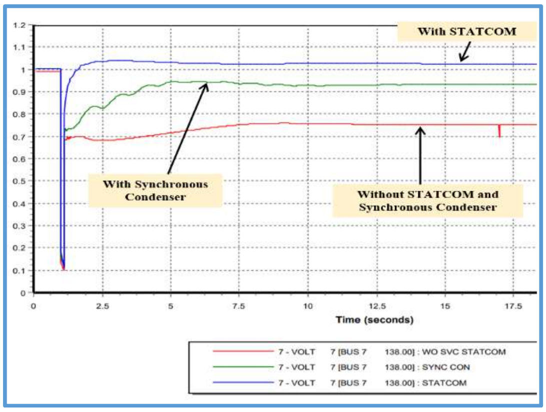


Figure-12

Figure-13

6. CASE STUDY

India has set a renewable energy target of 500 GW by 2030. Indian states of Gujarat and Rajasthan will be major contributors to the ambitious renewable energy capacity addition targets. Rajasthan has targeted setting up 30,000 MW of solar capacity by 2024-25 out of which 24,000 will be grid-connected/through solar parks, 4,000 MW decentralized solar plants and 1,000 MW each of roof top solar and solar pumps. Rajasthan also plans to generate 7,500 MW from wind generation till end of 2024-25. Presently, out of the total installed capacity of Rajasthan i.e. 27,000 MW, 15,000 MW is renewable generation capacity.

A replicated network model shown in **Figure-14** of the region in Rajasthan was considered for simulation studies. As can be seen from the network model that certain buses have major renewable generation with little conventional generation in the vicinity. For the sake of brevity, only the renewable generation capacities connected to such buses are shown in the network model. During the various outage scenario simulations, these buses showed a significant reduction in the short circuit power capabilities posing serious concerns related to system stability in the region.

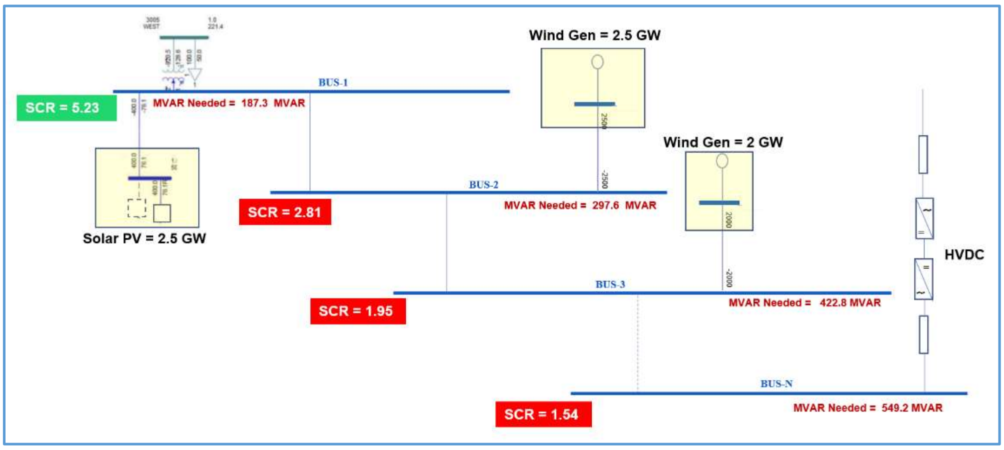


Figure-14

SCR was worked out at various nodes/buses with the method described earlier in section 3A. As can been seen from the simulation study model that certain system bus N has SCR levels just around 1.5 which is 50 % of the desired SCR level of minimum 3 at any node/bus. Approach outlined below was used to calculate the synchronous condenser ratings to restore the minimum SCR level of 3 at such system buses.

6A. Synchronous Condenser Rating Basis

Short Circuit Power:

- Calculate SCR at all nodes in the region
- Check for the issues of voltage regulation and reactive power deficit
- Select Synchronous Condenser rating based on above for maintaining SCR above requisite value

Inertia

- Calculate RoCoF during transient conditions
- Calculate the deficit in the inertia to maintain requisite RoCoF
- Select Synchronous Condenser to supplement the Inertia level

Simulation results suggest the addition of 1500 MVAR capacity synchronous condensers. **Figure-15** shows the improved SCR levels at the respective system buses after addition of the requisite MVAR capacities through synchronus condensers connection to such buses.

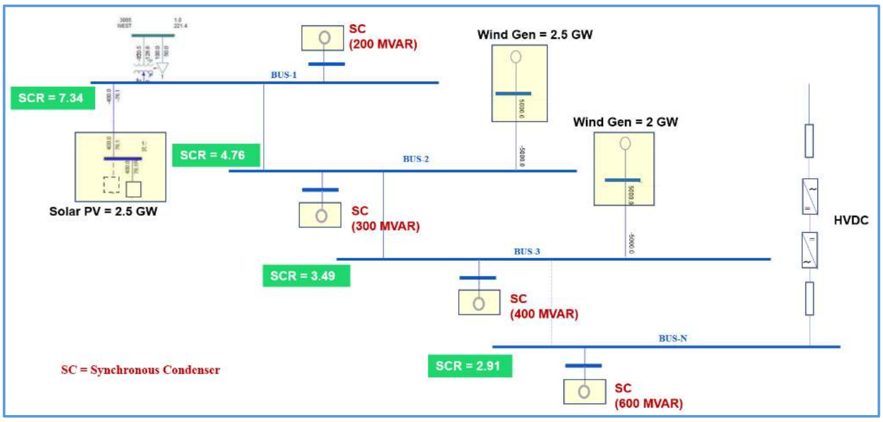


Figure-15

From the above simulation studies, it can be concluded that system studies need to be carried out by the system operator urgently to ascertain the type of ancillary services required at a particular location (considering planned renewable integration). These studies shall help in deciding the equipment and its details at that particular location. Synchronous condensers can be tailored to provide the required ancillary service based on specific requirements at a particular location/node.

7. SUMMARY AND CONCLUSIONS

Considering the effectiveness of synchronous condensers to provide inertia, system strength including transient capability to supply short circuit current and high reactive power support, synchronous condensers emerge as the strongest technical solution to deal with grid stability issues with increasing renewable integration into the Indian power network.

The exact locations of the synchronous condenser installations shall be finalized by the system operator based on the system studies considering the planned renewable integration. The system studies need to be carried out urgently by the system operator for deciding the location and type of ancillary service required. Also, presently very little clarity is available from regulatory side for compensation of the ancillary services in India.

System studies, identification of locations for installation of synchronous condenser, well planned pricing mechanism and regulatory policies are necessary for promoting investment in ancillary services. These systems need to be in place as soon as possible so that ancillary service providers are ready when there is a major shift from conventional to renewable generation.

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