ADDRESSING ISSUES IN RENEWAL INTEGRATION BY USING SPARE GENERATORS AS SYNCHRONOUS CONDENSER

D. K. Chaturvedi
Associate &General Manager (Retd.),
NTPC Ltd., Noida, India
dkc01851@yahoo.com

Abstract- This paper is about use of spare or retired turbo-generators as synchronous condenser. As discussed in this paper, synchronous condenser has superior performance as compared to other FACTS devices. Besides excellent reactive power management, it gives inertia to a weak grid. In large electrical network it improves system inertia, which helps in saving the grid under system transient condition by providing real power for short duration. Addition of a large number of machines will substantially increase inertia and make the grid stable under flexible operation of fossil fuel based thermal plant.

Key words – Variable Frequency Drive (VFD), Synchronous Condenser, Static Compensator STATCOM, Insulated Gate Bipolar Transistor (IGBT).

BACKGROUND

Renewable energy share to grid has been consistently increasing. Stringent target to increase renewable penetration has been set. This will reduce CO2 emission from conventional fossil fuel-based generation. It is worth to mention that a 4000MW coal-based power plant not only release more than 3400 tons of CO2 gas every hour but also eat up 2500 tons of Oxygen from the air. Big fans are provided to facilitate burning of coal. On annual basis this size power plant produces 28 million tons of CO2 and eat up 20 million tons of Oxygen. To cope up with environmental issues and lower emission by 30 percent, renewable generation penetration has been increased into the grid at a fast pace. The target of renewable generation by year 2022 has been set to a level of 175GW. It may be noted that average 50 GW of renewable generation replacing equivalent coal-based electricity generation will contribute at large to environment and will reduce 400 million tons of CO2 emission and save 300 million tons of Oxygen every year. However, this renewal power generation by solar power plants and wind power plants deprives the electrical network of reactive support and system inertia, which was earlier given by conventional machines to electrical network.

ISSUES WITH RENEWABLES

The renewable penetration for electricity supply is most sought option, but it has several issues, which needs to be addressed on priority:

- The renewable real power generation (from solar power plant and wind power plants) pattern is inconsistent, and generation will depend upon the variability of wind speed and solar heat falls per square metre.

- This variable generation due to unpredictable wind pattern and sometimes cloud movement will impose a challenge to ensure the power quality to the consumer and efficient grid operation under dynamic and transient condition.

- In solar generation, the accumulation of dust/dirt on solar panel will also severely affects the output from solar panels.

- As the point of connection of renewable power plant, the power is fed to the electrical grid through inverter. The conversion of DC output from solar panels is feed to IGBT based inverter, which converts the DC into AC and this output, which is not a pure sine wave, is send to grid through a power transformer. The output from renewable power plant is not a pure sinusoidal wave like that of conventional thermal and hydro power plants.

- Whereas, in case of conventional power plant the available reactive support at machine output is 50-60 percent of active power, contrary to this the reactive support at renewable power plant output is not available and has to be met only by external means.

MANAGING THESE CHALLENGES

The variable load demand from the unpredictable renewable output is met by augmenting this generation with pump storage hydro power plant or flexible operation of thermal plants.

The Gas based fast response alternatives can also meet the variable load while operating in conjunction with variable renewable generation.

In both cases a fast ramping of active power support is needed. This short duration power support can be from following available alternatives:

a. Support from existing nearby running thermal generators,

b. Support from machines running as Synchronous Condenser connected in the local electrical network

c. Battery support local to renewable power generation plant

d. Hydro power plant located nearby

e. Pump storage plant.

As the renewable power plant do not generate reactive power, availability of same has to be ensured by external means to ensure power quality. This reactive support during a) changing grid loading condition or b) changing renewable power generation can be achieved through external means.

COMPENSATION REQUIREMENT FOR RENEWABLES

It is important to understand that real power cannot travel in absence of reactive power. The reactive power facilitates transport of real (MW) power from the power generating station to the ultimate consumer. In electrical network synchronous generator and transmission lines delivers as well as absorb reactive power depending on network loading conditions. Other component like capacitor/shunt reactor are used to deliver/ absorb reactive power.

The reactive power is absorbed/delivered by transmission line based on its loading condition. At consumer end shortage of reactive power (MVAR) is many times met by provision of a variable capacitor bank.

In case of conventional fossil fuel based and hydro power plant, the electricity is generated from a turbo-generator coupled to turbine rotating at high speed. Similarly in case of Hydro power plant, generator coupled to turbine running at low speed. These rotating machines feed electricity to the network directly through a power transformer. The electricity generating machines not only transfer MW from the turbine to the high voltage electrical network, but also supply or absorb large amount of reactive MVAR to/from the associated electrical network.

When a large change from fossil fuel-based turbo-generators to solar power plant or wind power plants is planned, this imposes several challenges as discussed above. The output of these renewable plant is feed to the grid through an inverter and power transformer. This output of inverter send active power (useful part) to the grid depending on the power factor of the network at the point of connection. Therefore, this active power supplied to grid can be maximum, when the system power factor is Unity.

The power factor at the point of connection shall depend on

- Loading of transmission line
- Provision of capacitive/reactive compensation
- Proximity to hydro/gas /fossil fuel-based turbine generators.

The varying reactive power requirement at point of connection of renewable power plant (solar or wind) can be met very well by STATCOM or Synchronous condenser. Such FACTs device provisions will help to

- Meet system MVAR requirements of retiring generators and new renewable plants,
- Meet requirement of high system inertia,
- Low voltage ride through capability during peak condition
- Meet reactive MVA of HVDC
- Improve system stability for solar or wind plant weak isolated system.
- Improve power quality.

PERFORMANCE COMPARISION OF FACTS DEVICES

While comparing the performance of FACTS devices, it is seen that the synchronous condenser based solution are superior in performance. The comparison of STATCOM and Synchronous condenser is given in table below:

PERFORMANCE COMPARISON OF FACTS DEVICES			
Sl. No.	**Parameter**	**STATCOM**	**Synchronous Condenser**
1	Short Circuit Current	Poor	Good
2	Overload	Poor	Good
3	Response time	Excellent	Good
4	Inertia	Negligible	Good
5	Handling Transient – fault condition	Excellent	Good
6	Handling Dynamic cond.	Good	Good
7	Efficiency	99.2%	98.5%
8	Harmonic	Present	Nil

PROPOSED SYNCHRONOUS CONDENSER BASED SOLUTION

In present time the conventional generators are supporting the MVAR requirements of network by varying the field current. The fast response of generator is ensured for all dynamic as well as transient requirements of reactive power. The machines with static excitation system are of high initial response type excitation system and can feed MVAR to system within response time of less than 20 mS. Solutions are available to make brushless exciter type machines also as high initial response type matching response time to static excitation system. This facilitates use of generator with either brushless or static type excitation system to operate as synchronous condenser. The high ramp rate requirements can also be frequently met by such machine-based solution.

This paper suggests use of several Synchronous condenser machines connected to grid to maximise the real renewable penetration into the electrical network. Whereas the STATCOM can only support reactive power, the synchronous condenser can also give inertia to the electrical system, which could be useful in saving the grid by short duration active support. Few advantages of Synchronous Condensers are as listed in table above giving performance comparison.

It is important to note that generation/absorption of reactive power in range of 10MVAR-700MVAR (depending on unit size) can be achieved by consuming a meagre 200kW to 4000 kW power required to run a large size 3000 rpm generator as synchronous condenser. As example, by consuming approximately 4000KW, we can feed 700MVAR into the system from a synchronous condenser machine.

ADVANTAGES OF USING OLD EXISTING GENERATORS AS SYNCHRONOUS CONDENSER

The use of existing retired spare generators as synchronous condenser could help us in improving the grid stability and also power quality. The synchronous condenser also has several advantages, which makes it a must for system with large scale renewable integration. Some of the performance advantages are as follows:

- Meet system MVAR requirements arising out of retiring generators.
- Provide Inertia due to rotating heavy mass.
- Support frequency and active power short time variations.
- Low voltage ride through capability during peak condition.
- Facilitates dynamic compensation.
- To meet reactive MVA of HVDC.
- To improve system stability for solar or wind plant weak isolated system.
- Maintains power quality.
- High reliability and
- High overload capability.

SPARE GENERATOR AS SYNCHRONOUS CONDENSER – A NOVEL SOLUTION

Subsequent to addition of 175GW renewable generation, the power will be injected to the grid at several hundred points. The variability of load and generation will severely affect the extra high voltage network. This will require multipoint Reactive power support.

Similarly, a few hundred points in distribution network will also be requiring reactive power support.

Each of these points at generation, transmission and distribution level will be requiring necessary reactive power support (absorption or delivery) to facilitate smooth transportation of electricity and ensuring power quality right from generation to the end consumer. It is worth to mention again that reactive power do not travel far i.e. more than 100 kilometres from the point of injection.

Multipoint reactive power injection to grid can be partially met by using existing resources including spare as well as retired generators. On additional large number of synchronous machines and their operation as synchronous condenser could play a major role in enhancing the inertia of electrical network and lowering harmonic at different MVAR injection point, which could not be there in alternate FACTS based solution.

The use of spare generators as synchronous condenser could help us in improving the grid stability and power quality. This solution gives three phase balance pure sine wave output, thus has advantage over static VAR compensators, of not introducing harmonics in system rather lower the harmonic content.

SUGGESTED LOCATION

It is proposed to plan these machines at new locations as per system studies based on past data and considering future requirements. The major benefit of planning new installation is use of existing large rating spare 776MVA, 940MVA, 588MVA and 315MVA machines and those machines which have been retired in recent past. These installations can also be right at substation, where MVAR support is frequently required and adequate space to build facilities is available.

PROPOSED ARRANGEMENT OF SPARE/ RETIRED SYNCHRONOUS CONDENSER

Spare Generator/retired generator is accessed for healthiness of insulation system by conducting Residual Life Assessment (RLA) study prior to use as synchronous condenser. The other important aspects to be taken care are:

a) The main generator bearing is changed to thrust bearing. The new bearing should be same as used at the test bed setup.

b) The excitation system is to be static type to meet fast ramp rate requirements. Brushless excitation system needs modification to convert it to High Initial Response type.

c) The drive motor coupled to synchronous condenser will be driven using VFD.

List of equipments used in synchronous condenser scheme:

a. Main turbo-generator.

b. The bus bar connection between Generator, GT Bank, Generator Circuit Breaker, Excitation Transformer, PT&SP Cubicle.

c. The Surge Protection & Voltage Transformer (SP&VT) Cubicle.

d. Protection monitoring & control system.

e. Necessary HT Feeder to run VFD driven motor.

f. Necessary Low Voltage Switchgear and Air Conditioning System.

g. Generator Transformer Bank.

h. HV equipment bay connecting GT bank to grid.

i. Barring gear system and jacking oil system.

WHY LARGE HYDROGEN COOLED MACHINES ARE GOOD TO USE

It may be noted that hydrogen cooled machine insulation deteriorates at very low pace as compared to air-cooled machines. The basic two factors which result in longevity of hydrogen cooled machine insulation system are

- Machine insulation is in pressurized hydrogen and thus oxidation of insulation does not take place. The insulation deterioration is solely due to mechanical aging, e.g. rubbing of bar insulation.

- The hydrogen pressure increases the breakdown voltage of machine insulation system. The electrical stress seen by insulation system of hydrogen cooled machines is very low and thus avoid failure of insulation.

EXCITATION SYSTEM

Static excitation System is considered a better option performance wise. The static excitation system is high initial response type to handle grid dynamic condition during sudden load variations seen with renewable generation.

However in case of brushless type of excitation system, the response is sluggish as the machine time constant of exciter is added in response time.

Now, solutions are available to convert brushless type machine to a high initial response type machine. The modification involve replacement of diode wheel by new thyristor based rectifier wheel with blue tooth enabled firing circuit mounted on rotating rectifier wheel. This arrangement nullify the time delay introduced by exciter in conventional arrangement.

DRIVE MOTOR WITH VFD

Adequately sized 6.6kV motor feed from Variable Frequency Drive shall be used to synchronize the generator. The machine speed is increased to a speed more than 3000 r.p.m. and rated voltage is achieved by field control through excitation. After switching off the motor, machine is synchronised with the electrical network as and when rated speed is achieved.

THRUST BEARING

Necessary thrust bearing is to be provided between the drive motor and generator.

GENERATOR AUXILIARY SYSTEM & CONTROL PANELS

The existing generator auxiliary system and control panel is to be retained and healthiness of auxiliary system needs to be checked to ensure proper hydrogen pressurization, perfect sealing and lube oil flow. Necessary AC supply to auxiliaries is to be ensured.

LA & VT CUBICLE FOR GENERATOR PROTECTION.

GENERATOR TRANSFORMER BANK

The GT shall be sized to meet the MVA requirements as per Generator capability curve at 0- MW line and designed considering the desired operational ramp rate of 100MVA/minute.

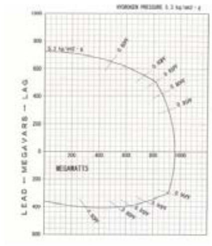

Figure-1 Capability Curve of Turbo Generator

HIGH VOLTAGE ELECTRICAL BAY

All equipment coming in the conventional generator bay are also provided in synchronous condenser scheme.

EQUIPMENT FOUNDATION

The installation of synchronous condenser job involves in casting a new foundation and building for placing:

- New Generator, auxiliary system skids, Excitation system and Control panels,
- GT bank and electrical bay equipment,
- Drive motor along with VFD,
- Thrust bearing between drive motor and generator,
- Barring gear and jacking oil system,
- Air conditioning system for Static Excitation, Generator Relay & Control Panels,

Suggested building layout of new installation of Synchronous Condenser is as below in figure-1 & 2.

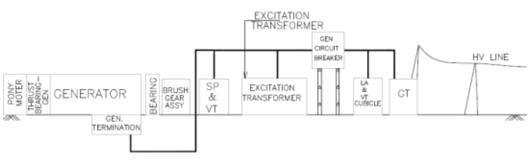

Figure-1: Synchronous Condenser Building Equipments

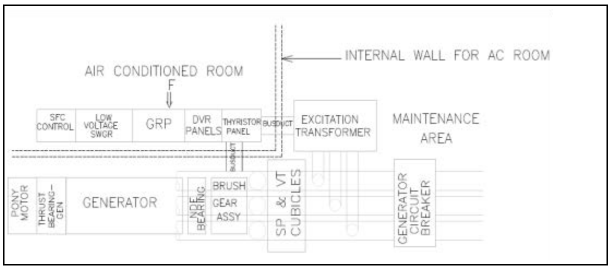

Figure 2: Synchronous Condenser Building – Equipment Layout

CONCLUSION

As discussed above, the Indian grid will be severely affected by large scale renewable integration. The sudden voltage and frequency variations expected on the grid will need a good solution to quickly add MW and MVAR as and when system need. The synchronous condenser could emerge as right solution to quickly add MVAR into the system, as and when required. It will increase the inertia of electrical network by addition of several machines as synchronous condenser. This will save the network by real power support for a short duration during a transient condition. As Synchronous condenser output is pure sine wave, it will improve the power quality and help in maintaining the system voltage profile. The suggested use of existing large size spare generators and large size hydrogen cooled retired generators will reduce the per MVA cost of installation to a great extent. This could be techno-economically a good alternative to ensure power quality and support in future grid with large renewable mix.

REFERENCES

1. Planning the Future Grid with Synchronous Condensers; J. P. Skliutas, R. D'Aquila, J. M. Fogarty, R. Konopinski, P. Marken, C. Schartner, G. Zhi, General Electric Company, United States and Canada, CIGRE USA 2013

2. Converting Synchronous Generators into Synchronous Condenser by Dr J M Fogarty

BIOGRAPHICAL INFORMATION

Mr. D.K. Chaturvedi is post graduate from IIT Roorkee, India. He is presently Associate & General Manager (Retired), NTPC. He is expert member from India in IEC committee and CIGRE on Rotating Electrical machines.

Several of his papers have been published in CIGRE Paris session covering vast area of electrical machines, includes Generator stator water system, Machine Monitoring and Life assessment techniques, Trend in Generator Excitation System and Design Requirement of motors for VFD application. He is one of main author of 'CIGRE guide on Machine Diagnostic and Monitoring' and convener of CIGRE brochure on 'Use of IE3 motors in Existing Plants for CO2 Emission Reduction', published in June 2018.

He is presently **convener of CIGRE Joint Working Group SC-A1/C4** on 'Guide on the Assessment, Specification and Design of Synchronous Condensers for Power Systems with Predominance of Low or Zero Inertia Generators'.