Grid Controller of India Limited
(formerly Power System Operation Corporation Limited)
National Load Despatch Centre (NLDC)

Procedure

for

Assessment of Dynamic Reactive Reserve

Prepared in Compliance

to

Clause 39 (6) of Central Electricity Regulatory Commission
Indian Electricity Grid Code
Regulations, 2023
September 2023

Contents

Procedure for Assessment of Dynamic Reactive Reserve

1. Background

1.1 This procedure is in accordance with regulation 39(6) of the Central Electricity Regulatory Commission (Indian Electricity Grid Code) Regulations, 2023 (hereinafter referred to as the "IEGC, 2023"). Relevant extracts are quote below.

Quote

.....(6) NLDC, RLDCs and SLDCs shall assess the dynamic reactive power reserve available at various substations or generating stations under any credible contingency on a regular basis based on technical details and data provided by the users, as per the procedure specified by NLDC

Unquote

1.2 As per Regulation 29(15) of IEGC, 2023, NLDC, RLDCs, SLDCs, and users shall operate in a manner to ensure that the steady state grid voltage as per the CEA Grid Standards remains within the following operating range:

Voltage (kV rms)		
Nominal	**Maximum**	**Minimum**
765	800	728
400	420	380
230*	245*	207*
220	245	198
132	145	122
110	121	99
66	72	60
33	36	30

As per CEA Manual on Transmission Planning Criteria, 2023.

1.3 As per Regulation 3(c) of CEA Grid standards, temporary over voltage due to sudden load rejection shall remain within the limits specified below:

S. No.	Nominal System Voltage (kV rms)	Phase to Neutral Voltage (kV peak)
1	765	914
2	400	514
3	220	283
4	132	170

Provided that for the voltage level below 132 kV, the temporary over voltage limits as given in Table shall be decided by the State Commission in the respective State Grid Code

1.4 As per Regulation 3(e) of CEA Grid standards, maximum fault clearing time is shown in below table

S.No.	Nominal System Voltage (kV rms)	Maximum Time (in milliseconds)
1	765 and 400	100
2	220 and 132	160

1.5 Dynamic reactive reserves are essential for angle as well as voltage stability in the synchronous system.

1.6 As per 4.4.2.1 of the CEA Manual on Transmission planning criteria 2023, the list of credible contingencies under steady state is as follows:

a. All the equipment in the transmission system shall remain within their normal thermal and voltage ratings after outage / loss of any one of the following elements (called single contingency or 'N-1'), but without load shedding /rescheduling of generation

i. Outage of a 132 kV single circuit

ii. Outage of a 220 kV single circuit

iii. Outage of a 400 kV single circuit (with or without fixed series capacitor)

iv. Outage of an Inter-Connecting Transformer (ICT) / power transformer

v. Outage of a 765 kV single circuit

vi. Outage of one pole of HVDC bipole

b. The angular separation between adjacent buses under 'N-1' shall not exceed 30 degrees.

c. 'N-1' criteria for FACTS devices may not be considered, however studies may be carried out to address the issues like reduction in transfer capability, restriction on generation evacuation etc. in case of outage of FACTS devices.

1.7 Most generators, synchronous condensers and static var compensators of a power system regulate the supply of reactive power generation during steady state and contingencies. CEA standards for connectivity mandate the inverter-based resources to operate in reactive priority mode for fault ride through.

1.8 It is well known that reactive power cannot be transmitted over long distance. Even if a resource has a large reserve with respect to its physical limit, its effective ability to help containing remote incidents may be limited. In other words, in large systems, reactive reserves cannot be obtained by merely summing up individual reserves.

1.9 The procedure lays down a methodology for measurement-based assessment of dynamic reactive reserves available at the terminals of the energized reactive resources.

2. Scope

The procedure shall apply to State Load Despatch Centres (SLDCs), Regional Load Despatch Centres (RLDCs), National Load Despatch Centre (NLDC) and all users to the extent applicable.

3. Reactive power resource

3.1 Reactive power resources are generally differentiated between static and dynamic resources and are usually defined by reactive power output controllability once connected to the grid.

3.2 Static reactive resources are the reactive resources that have fixed reactive power output at their nominal voltage, and their capability varies according to voltage squared. These devices are switched in or out of service based on system conditions. Examples of Static reactive resources include shunt reactors, shunt capacitors (excluding HVDC automatic control), transformer tap change: generator transformer and inter-connecting transformer, HVDC filter bank. These equipments do not provide dynamic reactive support and shall not be considered while assessing the dynamic reactive reserve margins.

3.3 Dynamic reactive resources are the reactive resources that adjust reactive power output automatically in real-time over a continuous range within a specified voltage band in response to changes in grid voltage. These resources operate to maintain a set point voltage or operate in a voltage droop mode. Examples of Dynamic reactive resources include Synchronous generators, Synchronous condensers, static VAR compensators (SVC), STATCOM, VSC-based HVDC, non-synchronous inverter-based resources enabled to provide reactive power support.

3.4 All generating stations shall be capable of supplying reactive power support so as to maintain power factor at the point of interconnection within the limits of 0.95 lagging to 0.95 leading as per the CEA Connectivity Standard Regulations.

3.5 All generating stations connected to the grid shall generate or absorb reactive power within the capability limits of the respective generating units, where capability limits shall be as specified by the OEM.

4. Submission of reactive capability and controller settings of reactive resources

4.1 The synchronous generators connected to the grid shall submit their PQ capability curve of

all the commissioned generating units to the respective RLDC/SLDC. The limitations in providing dynamic reactive support such as armature thermal limits, rotor current limits, under excitation limits & other limits if any shall also be marked on the PQ capability curve. AVR settings for synchronous machines, Controller settings for IBR shall be submitted.

4.2 All the existing IBR-based resources shall submit PQ capability curve at Point of Interconnection to RLDC/SLDC with due consideration of over voltage settings, over current settings, and other limitations of the IBR system.

4.3 All the other users owning or operating the dynamic reactive resources such as FACTS devices, HVDC shall submit the implemented PQ or VQ capability curves as applicable to NLDC/RLDC/SLDC.

4.4 As per the Regulation 40(3) of the IEGC, 2023 the reactive power capability tests shall be performed once every five (5) years or whenever major retrofitting is done. If any adverse performance is observed during any grid event, then the tests shall be carried out even earlier, if so, advised by SLDC or RLDC or NLDC or RPC, as the case may be. Further, the Reactive Power Capability tests may also be advised by SLDC or RLDC or NLDC or RPC, as the case may be if it is observed that the generator/IBR/condenser/FACTS/HVDC(VCC) is not able to provide sufficient reactive power support as per the capability curve submitted by the respective user. Revised capability curves and technical data shall be submitted to the respective LDC.

5. Computation of Dynamic reactive power reserves

5.1 Reliable reactive reserve is the amount of reactive reserve in pre-contingency to ensure that a transient or post-transient voltage collapse does not occur following a disturbance.

5.2 The computation of dynamic reactive reserve is computed for the buses where dynamic reactive capability is available.

5.3 The dynamic reactive power reserves are computed by comparing the actual interchange of reactive power at HV side of reactive power resources as mentioned above in section 3 with the dynamic reactive capability furnished by the respective users. During computation

availability of resources on bar shall be factored suitably.

5.4 The voltage being local phenomenon, the dynamic reserves shall be computed at HV side of reactive power resources. The group of tightly coupled buses may be grouped as voltage zones. The zoning may be done based on analysis of the historical data or any other scientific approach may be considered.

5.5 The dynamic reactive reserve of a device is measured as the difference between its present VAR output and its maximum var output in both directions. Its maximum VAR output is usually defined as that which can be sustained for an extended period (i.e., 30 minutes or longer).

5.6 The reactive power limits are to be assessed at the point of interconnection after factoring drops in GT/UAT or collector system in the case of IBR.

5.7 The reactive power limits to be considered for different elements are given below:

a) **Synchronous Generators & Condensers:** All synchronous generators are having D-shaped PQ capability curves. Further, D Curve is limited by field current, load angle, etc. The Q limits for synchronous generators corresponding to 40%, 55%, 75%, and 100% generation levels can be modeled as limits which can be revised as per the requirement. Synchronous Condensers have reactive power capability similar to synchronous generators and are generally capable to provide the reactive support to maintain voltages within desired limits under changing load conditions and contingency situations.

Illustration: The reactive power limits for one sample unit having capacity of 500 MW and operating at 400 MW is given below.

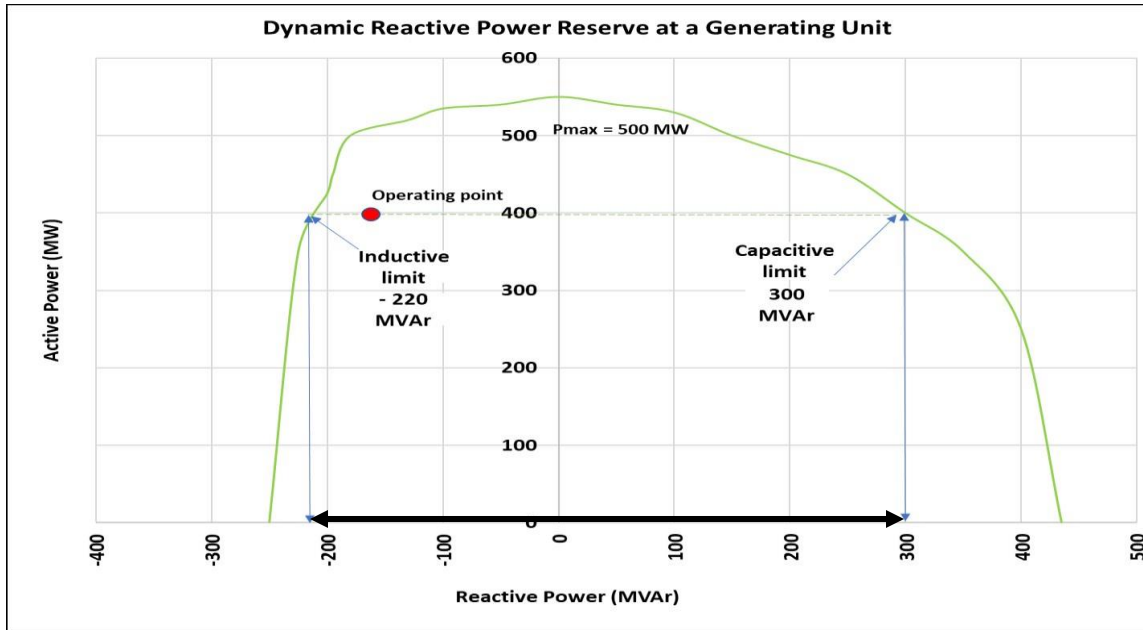| Sl No	Generating Station	On Bar Active Capability	Operating Point	On bar reactive Capability at that bus in MVAr	
		MW	MW	Qmax (+)	Qmin (-)
1	Unit 1 at Station A	500	400	300	-220

Figure 1: Reactive power limit of a synchronous Generator (Green shade) and synchronous condenser (Black shade)

b) **IBR-based Resources**: Grid Code mandates all IBR- based resources to be capable of supplying reactive power support so as to maintain power factor at the point of interconnection within the limits of 0.95 lagging to 0.95 leading as per the CEA Connectivity Standard Regulations. The PQ capability at POI is known for each RE station by the capability test and modeling studies which are carried out as part of the commissioning / FTC procedure. This PQ capability at POI is to be considered. **Illustration:** An IBR having maximum capability of 250 MW and operating at 200 MW with reactive power absorption of appx 30 MVAR. Then as per the capability curve given below, the plant can vary its reactive power within 66 MVAR absorption to 66 MVAR injection considering the limits of 0.95 lagging to 0.95 leading as per the CEA Connectivity Standard Regulations.

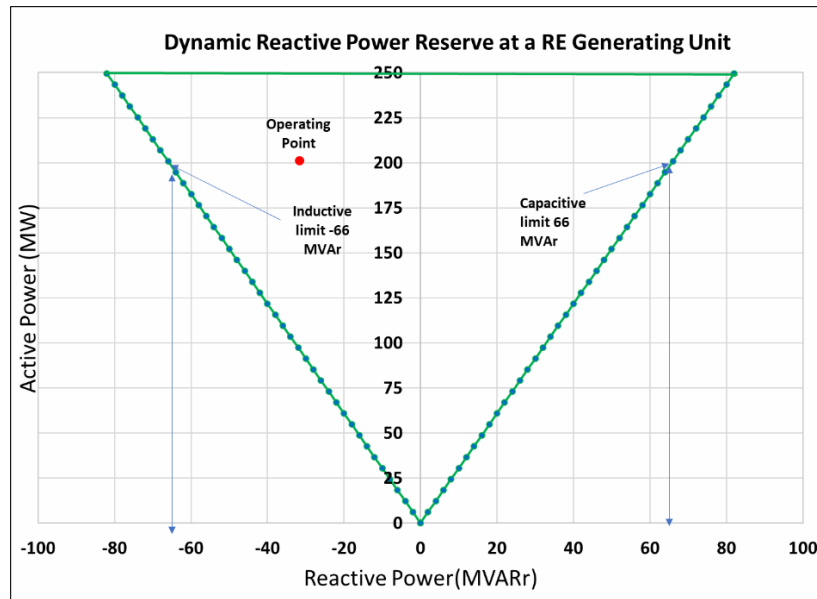| Sl No	Generating Station	Installed Capacity	Operating Point	On bar reactive Capability at that bus in MVAr	
		MW	MW	Qmax (+)	Qmin (-)
		A	B	C	D
1	IBR – A	250	200	66	-66

Figure 2: Reactive power limit of Inventor based Resources

c) **SVC, STATCOM:** The FACTs device such as SVC, STATCOMS operates w.r.t Voltage on a slope with a dead band. The VQ capability of these devices is to be considered.

Illustration: The V-Q curve given below shows a limit of dynamic reactive reserve for the STATCOM having the reactive capability of 2 x 100 MVAR.
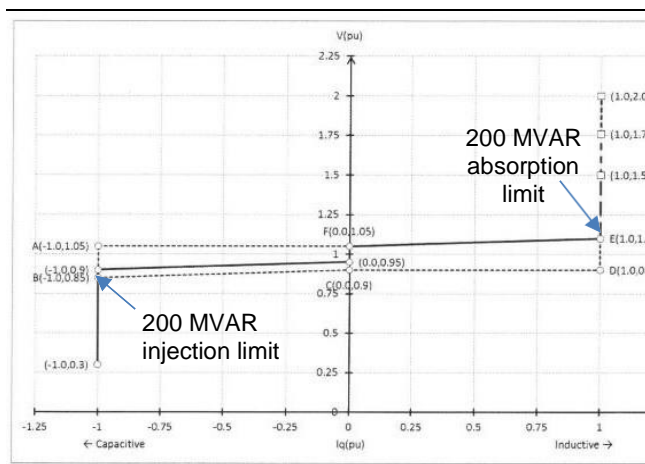

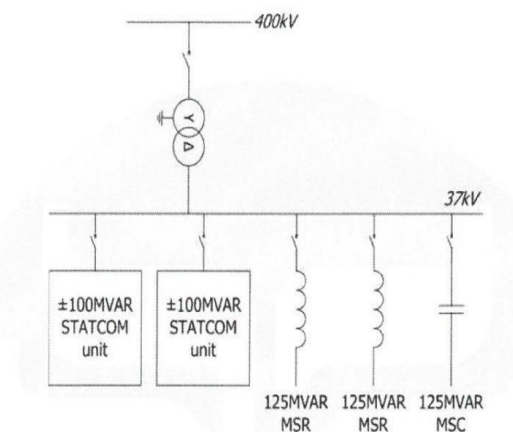*Figure 3: voltage and current output characteristics of 2 x 100Mvar STATCOM*

Figure 4: Schematic diagram of STATCOM Station

d) **HVDC(VSC):** The PQ capability curve of VSC based HVDC is to be considered for the reactive power limits.

Illustration: Each monopole of VSC Pugalur-Thrissur at each station is able to deliver/consume minimum reactive power of value equal to 330MVar at any active power level up to rated power (1000MW). The above capability requirements are valid for AC system voltage between 380-420 kV. For voltages outside the continuous limits the reactive power capability may be reduced. When operating at zero active power level the reactive power capability of each converter (both inductive and capacitive) shall be at least 50% of its MVA rating(550MVAR).
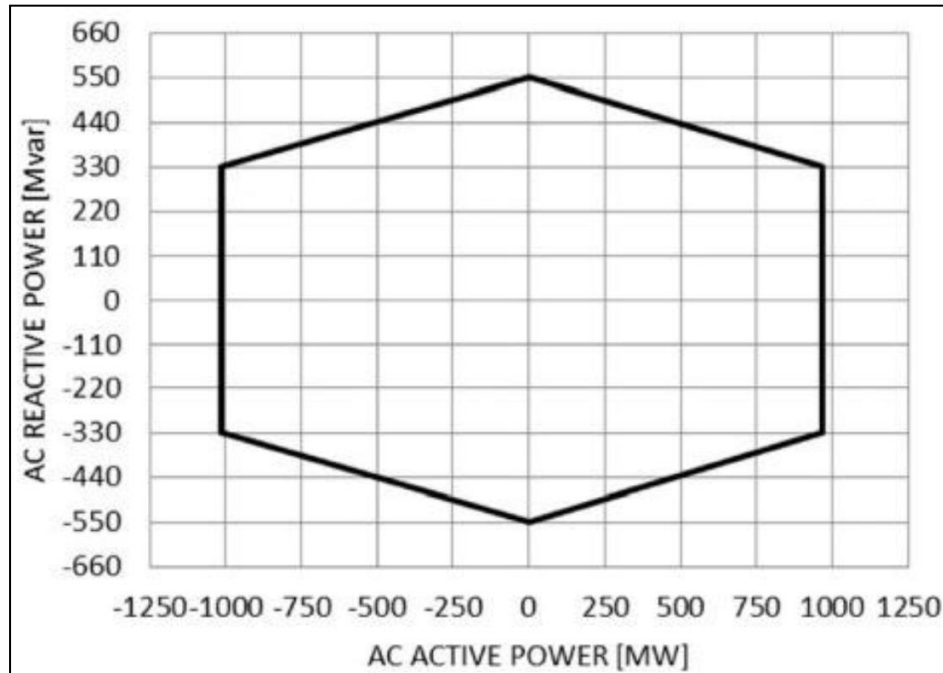
Figure 5: P-Q Capability curve of VSC Pugalur-Thrissur

5.8 The capability depends on the currently active power "P" level in the case of a synchronous generator, condenser, IBR, and HVDC. Whereas it is based on the present voltage level "kV" in the case of FACTs devices.

5.9 Short-term overloading of reactive reserve resources shall be reserved to handle contingencies; however, overloading shall not be considered a part of the reserve in normal steady state operation.

5.10 The dynamic reactive reserve (DRR) of a device is measured as the difference between its present var output and its maximum steady state var output viz capability in both directions.

The maximum var output viz capability at the current condition is derived as explained in Clause 5.7. The dynamic reactive power reserves shall be assessed & monitored in real-time as per

Format-IA, Format-IB & Format-IC for different dynamic reactive resources.

5.11 The sample illustration is explained in **Annexure-2**

6. Monitoring

6.1   Any short-term derating of reactive capability shall be immediately reported by utility to SLDC/RLDC.

6.2   No unit equipment replacement or modification that reduces the reactive capability of the reactive reserve-providing unit shall be undertaken without approval from SLDC/RLDC.

6.3   High reactive loading and reactive oscillations on generation units shall be immediately communicated to the SLDC/RLDC.

6.4   Data from PMU shall be used to assess the performance of dynamic reactive resources during transient conditions SLDC/RLDC shall monthly analyze the periods when the reactive reserve performance is below the declared capability.

7. Furnishing telemetered data

7.1 The telemetry of reactive power resources shall be ensured at SLDC/RLDC comprising of analog and digital signals/data as per First Time charging procedure.

7.2 In case of interruptions, action shall be taken to restore the same. During the intervening period, data shall be provided over email.

7.3 All users shall endeavor to ensure healthy & reliable real-time data at all times.

7.4 Measurement points for monitoring/assessment of dynamic reactive power reserves:

Illustration **for telemetry of Reactive power:** The reactive power assessment of various

reactive power sources shall be done at the point M1 as shown in figure below:
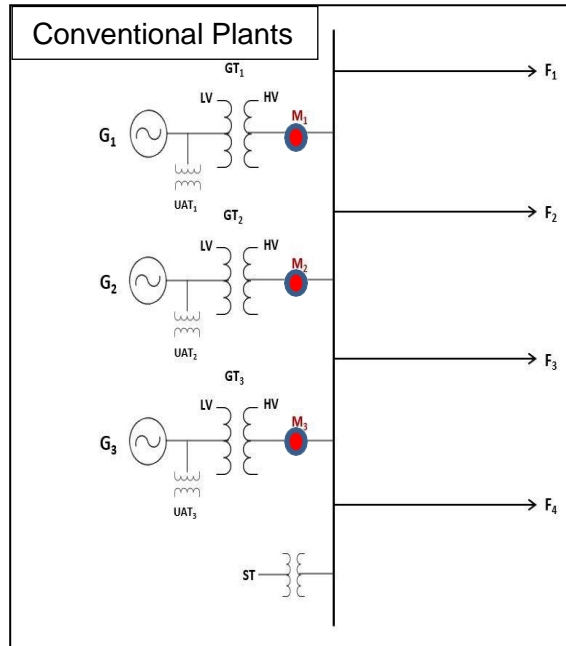
a) Conventional Power Plants

Figure 6: Schematic of Reactive Power Assessment at Conventional Plants
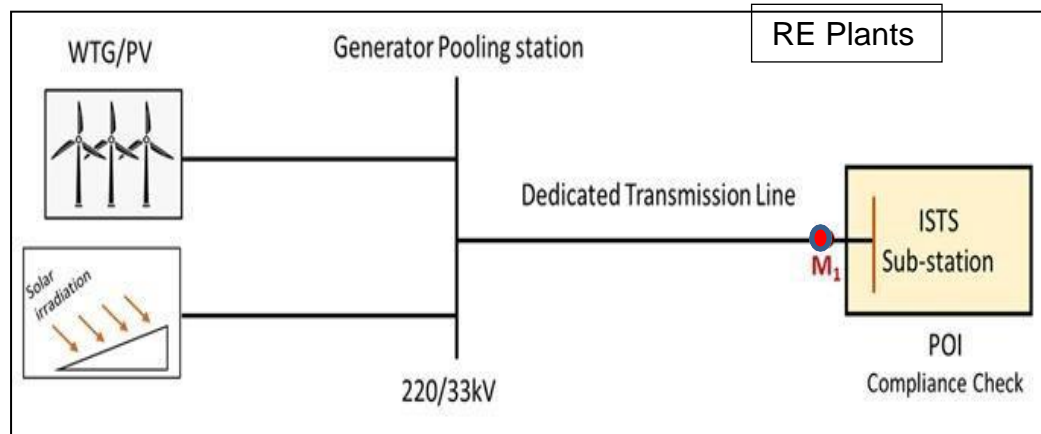
b) Invertor Based Resources

Figure 7: Schematic of Reactive Power Assessment at RE Plants
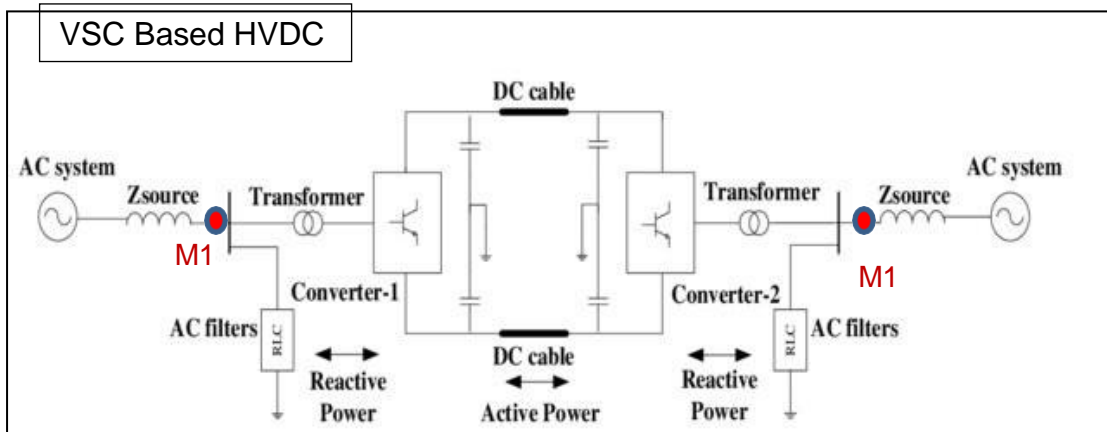
c) VSC based HVDC

Figure 8: Schematic of Reactive Power Assessment at VSC based HVDC
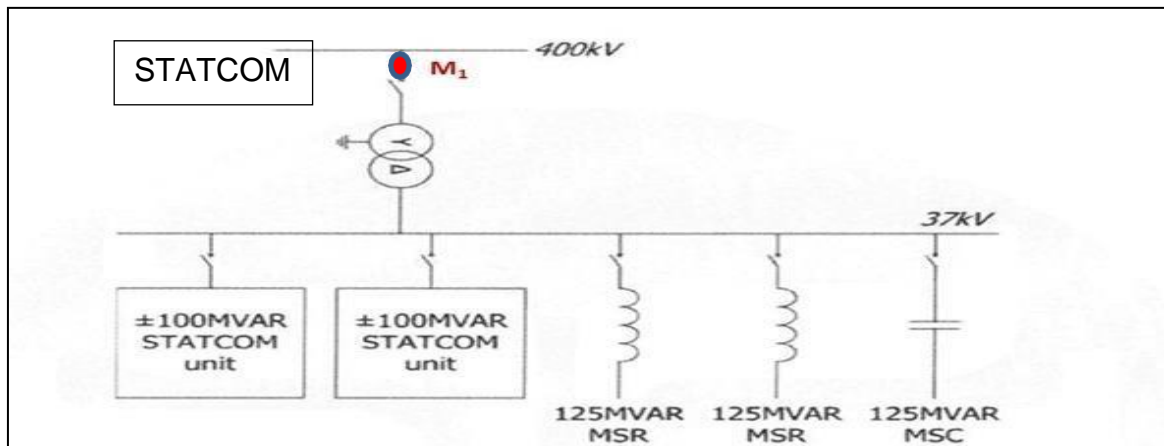
d) STATCOM

Figure 9: Schematic of Reactive Power Assessment at STATCOM

8. Revision of Procedure

The procedure shall be reviewed and revised by NLDC after stakeholder consultation and with intimation to the Commission.

Under exigencies, the procedure shall be reviewed and revised by NLDC with intimation to the Commission. Stakeholder consultation shall follow subsequently.

Annexure-I- Formats

Format-IA- for Generating stations / Condenser / IBR

Sl No	Generating Station	Installed Capacity	On Bar Active Capability	On Bar Current Generation	On bar reactive Capability at that bus in MVAr		Actual Reactive Injection (+)/ Absorption (-) in MVAr	Dynamic reactive power reserves in MVAr	
		MW	MW	MW	Qmax (+)	Qmin (-)		Qmax (+)	Qmin (-)
		A	B	C	D	E	F	G=D-F	H=E-F
1									
2									

Format-IB- for STATCOMs

Sl No	Substation Name	Capacity	Voltage at the bus	Reactive Capability at that bus in MVAr		Actual Reactive Injection (+)/ Absorption (-) in MVAr	Dynamic reactive power reserves in MVAr (Under Contingency)		Static Reactive Power Reserves	
		MVAR	kV	Qmax (+)	Qmin (-)		Qmax (+)	Qmin (-)	Reactor Absorption (-) in MVAr	Capacitor injection (+) in MVAr
		A	B	C	D	E	F=C-E	G=D-E	H	I
1										
2										

Format-IC- for HVDC(VSC)

| Sl No	Substation Name	Capacity	Voltage at the bus	Active Power	Reactive Capability at that bus in MVAr		Actual Reactive Injection (+)/ Absorption (-) in MVAr	Dynamic reactive power reserves in MVAr	
		MW	kV	MW	Qmax (+)	Qmin (-)		Qmax (+)	Qmin (-)
		A	B	C	D	E	F	G=D-F	H=E-F
1									
2									

Annexure-II-Sample Computation

Sample computation demonstrating the methodology

I. Generating stations / Condenser / IBR

The example shows an assessment of dynamic reactive reserve for the Talcher stage 2 generating station. The generating station has four units of 500 MW each with an installed capacity of 2000MW. One of the units is considered to be under outage. Thereby On bar capability is 1500MW. The on-bar units are generating 1500MW.

Sl No	Generating Station	Installed Capacity	On Bar Active Capability	On Bar Current Generation	On bar reactive Capability at that bus in MVAr		Actual Reactive Injection (+)/ Absorption (-) in MVAr	Dynamic reactive power reserves in MVAr	
		MW	MW	MW	Qmax(+)	Qmin(-)		Qmax(+)	Qmin(-)
		A	B	C	D	E	F	G=D-F	H=E-F
1	Talcher Stage 2	2000	1500	1500	900	-585	-400	1300	-185
2									

The information is shown on the station capability curve derived from unit wise capability curve for the purpose of illustration. The operator would look at the table above.
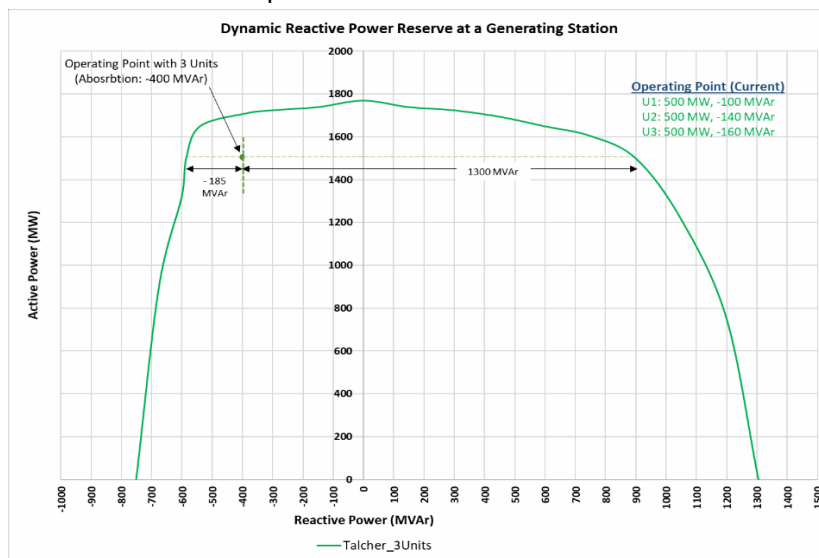
In case further details are required the unit-wise information on the capability curve may be seen.

II. STATCOM

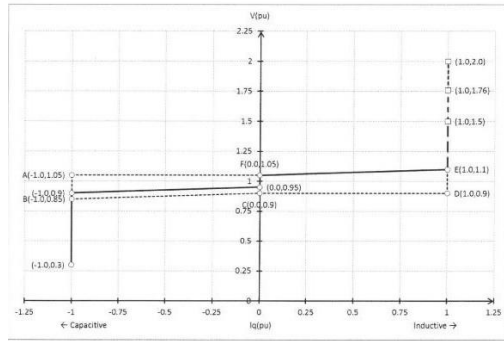The STATCOM operates w.r.t Voltage on a slope with a dead band.

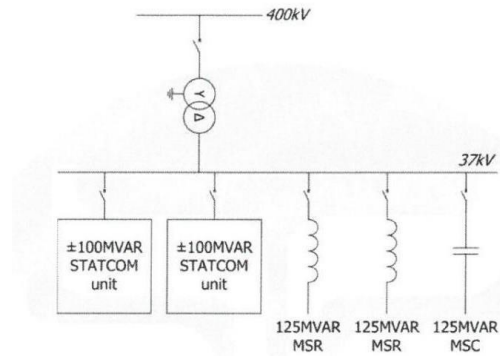Figure-1 Power system voltage and current output characteristics of 2 x 100Mvar STATCOM

Figure2-Schematic diagram of STATCOM Station

Location: Trichy/Ghanapur/Udamalapet

The example shows an assessment of dynamic reactive reserve for the STATCOM having the reactive capability of 2 x 100 MVAR. The 2X125 MVAR MSR and 125 MVAR MSC are mechanically switched devices and hence do not qualify as dynamic reactive devices.

Sl No	Substation Name	Dynamic Capacity	Voltage at the bus	Reactive Capability at that bus in MVAr		Actual Reactive Injection (+)/ Absorption (-) in MVAr	Dynamic reactive power reserves in MVAr (Under Contingency)			
		MVAR	kV	Q_{max} (+)	Q_{min} (-)		$Q_{max}(+)$	$Q_{min}(-)$		
		A	B	C	D	E	F=C-E	G=D-E		
1	X station	200	418	200	-200	-30	230	-170		
2										

III. HVDC(VSC)

Each pole has a certain limit for a particular active power level. Let us understand using an example. Each pole of VSC-based HVDC in the SR region has the capability of 550 MVAR at 0MW and 330MVAR at 1000MW for each pole.

Sl No	Substation Name	Capacity	Voltage at the bus	Active Power	Reactive Capability at that bus in MVAr		Actual Reactive Injection (+)/ Absorption (-) in MVAr	Dynamic reactive power reserves in MVAr	
		MW	kV	MW	Qmax (+)	Qmin (-)		Qmax (+)	Qmin (-)
		A	B	C	D	E	F	G=D-F	H=E-F
1	Pugalur-Trissur @ Trissur	2000	418	600	968	-968	-400	1368	-568
2									

Note: For the purpose of simplicity constant slope is used for PQ capability. However, we may have to use the exact relation during computation in SCADA.

In the above example, the actual flow of 600MW (300MW each pole) and the capability at that active power based on capability curve works out to 968MVAR (484 MVAR each pole).