Technical Sessions

1. Planning and Operation of Large Interconnected System – Critical Issues.
2. Protection Aspects of Large Interconnected power system.
3. FACTS for Dynamic Compensation in Power Transmission.
4. Power system simulation case studies using MiPower software.
5. Panel Discussions

Planning and Operation of Large Interconnected System – Critical Issues

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Introduction

The 90's was characterised by a boost in the interconnection projects either among isolated systems or for strengthening electric pools already interconnected.

This trend was experienced world-wide and has accelerating in many regions

The main aim is

- On decreasing their operation costs through better resource management
- To access to new sources of electric supply, which permits to reach more flexibility in the management of electric power systems.

Introduction

The electricity markets has introduced new factors in the network management, mainly related to:

- High degree of uncertainty for the future generation expansion;
- Growth of distributed generation on MV and even LV level;
- Lack of direct control from the system operator in the length of time between project initiation and completion for new generation;
- Greater difficulty in the realisation of new network reinforcements considering the multiplicity issues in executing projects including many owners;
- Increased number of eligible customers able to get energy wherever economically convenient;

Network capacity planning

Deep review of network capacity planning is needed considering the above factors

In the past, where the planner was able to carry out the optimal choice with limited risk, or, in some cases, without risks and also without uncertainty.

An important requirement deriving from the new environment and the consequent evolution of the planning process is in the need of operating the networks with a greater flexibility.

This might be obtained by strengthening power corridors with the construction of new lines but is poised with many ROW issues along with environmental obstacles and authorisation processes.

Worldwide the critical issues

Investment in the transmission grid has not kept up with the growth in demand and increase in energy trading;

Regulatory uncertainty has delayed the investment in the grid and there is a lack of incentives for transmission network companies to upgrade their grids, due to costs and environmental constraints;

Electricity market environment, many existing transmission and distribution systems may have to be operated close to their operating limits in terms of voltage, thermal and power transfer capabilities, and system stability constraints;

Lack of **fast dynamic control** resources such as FACTS and HVDC, which can be used to re-direct power flows among the available transmission corridors, and provide dynamic voltage support;

Critical Issues Indian context

The transmission system has not got sufficient investment both at State and Central levels commensurate with the capacity addition and demand growth

There is lack of active power control in optimising the existing resources due to

- Inadequate and near absence of dynamic var
- WAMS
- Wide Area Control

Transmission Line Loadability

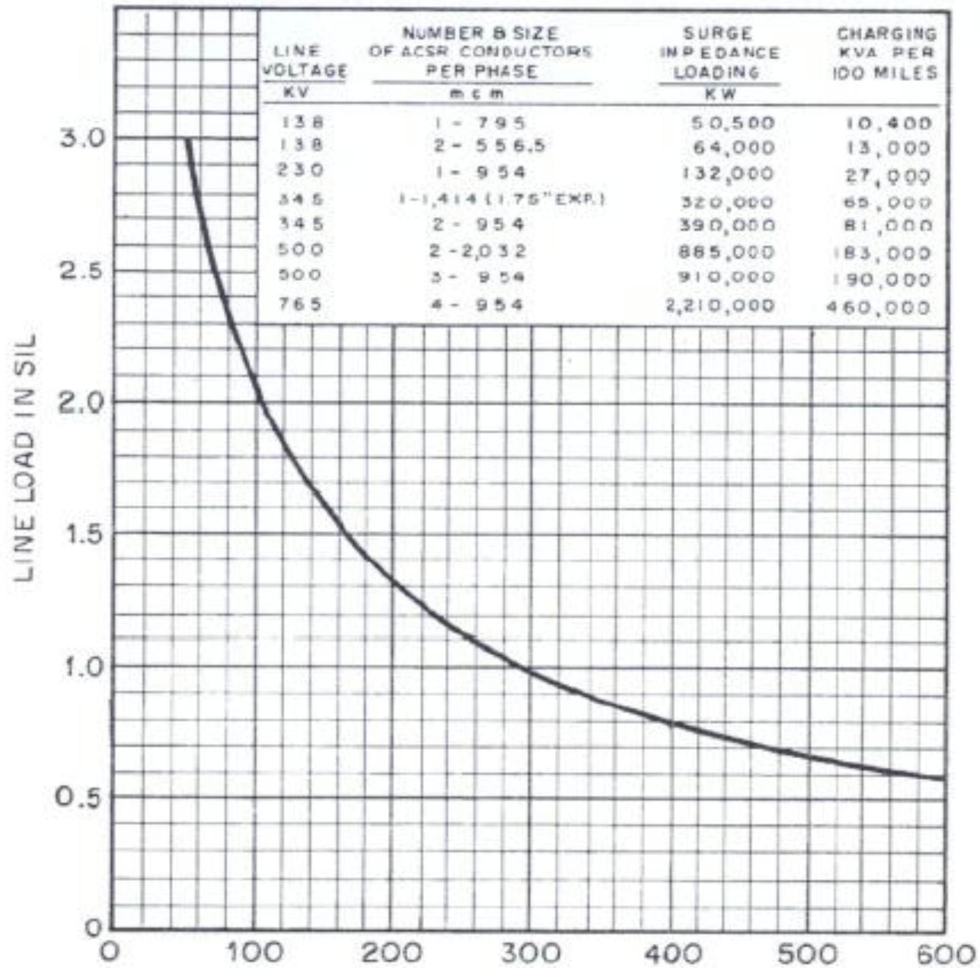
Power transfer capability curves is generally defined by “St. Clair curves” for planning engineers ever since their publication in 1953

The curves are defined based on voltage & stability limits

The curves defines the loadability in terms of SIL for line lengths upto 400miles

St. Clair Curve

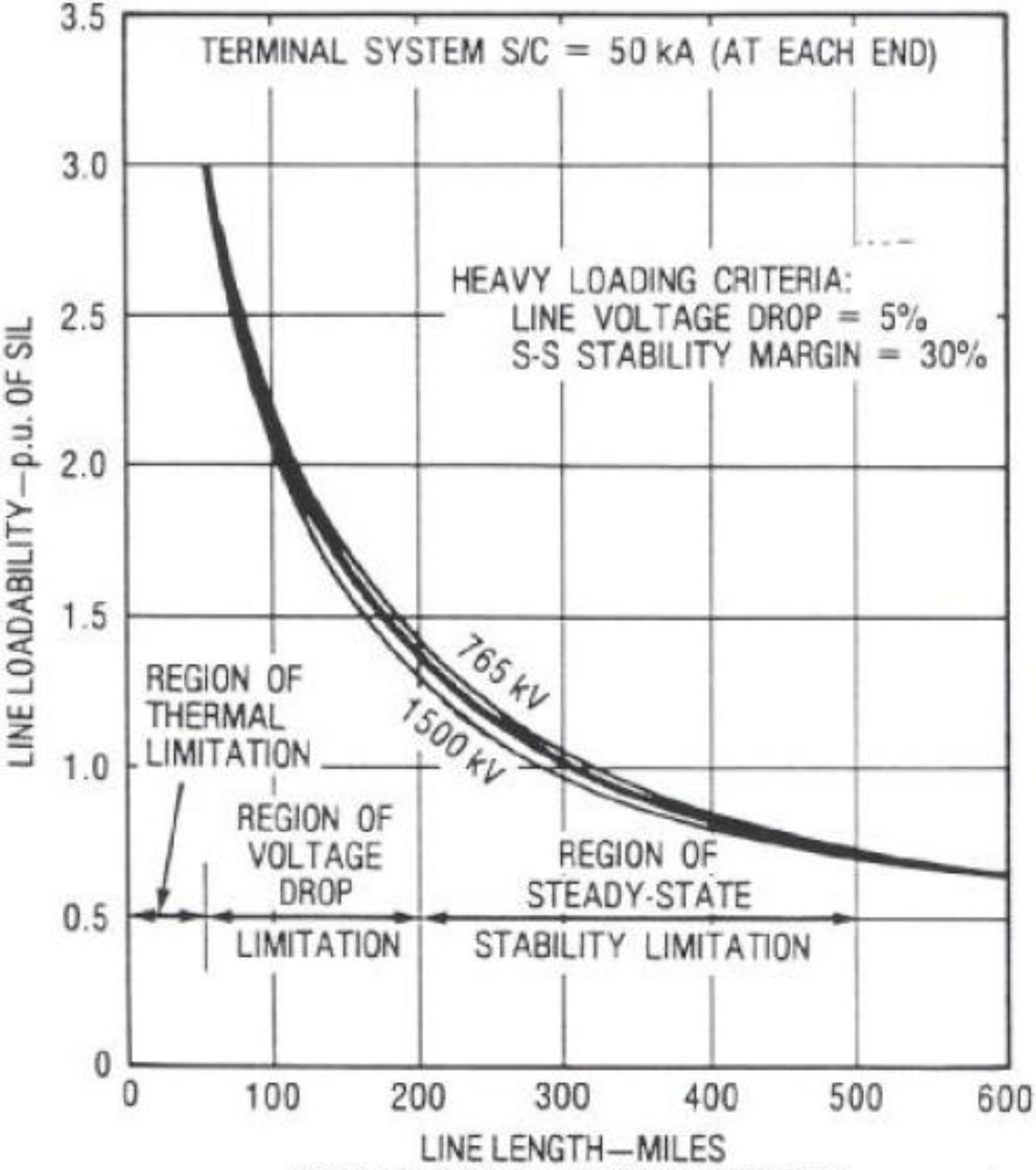
TRANSMISSION LINE CAPABILITY IN TERMS OF SURGE IMPEDANCE LOADING



LINE VOLTAGE KV	NUMBER & SIZE OF ACSR CONDUCTORS PER PHASE mcm	SURGE IMPEDANCE LOADING KW	CHARGING KVA PER 100 MILES
138	1 - 795	50,500	10,400
138	2 - 556.5	64,000	13,000
230	1 - 954	132,000	27,000
345	1-1,414 (1.75" EXP.)	320,000	65,000
345	2 - 954	390,000	81,000
500	2 - 2,032	885,000	183,000
500	3 - 954	910,000	190,000
765	4 - 954	2,210,000	460,000

LINE LENGTH IN MILES
WITH NO SERIES COMPENSATION

Source:
R. D. Dunlop, R. Gutman and P. P. Marchenko: "Analytical Development of Loadability Characteristics for EHV and UHV Transmission Lines," IEEE Transactions on Power Apparatus and Systems, Vol.PAS-98, No.2 March/April 1979.


TERMINAL SYSTEM S/C = 50 kA (AT EACH END)
HEAVY LOADING CRITERIA:
LINE VOLTAGE DROP = 5%
S-S STABILITY MARGIN = 30%
765 kV
1500 kV
REGION OF THERMAL LIMITATION
REGION OF VOLTAGE DROP LIMITATION
REGION OF STEADY-STATE STABILITY LIMITATION
LINE LOADABILITY—p.u. OF SIL
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
100
200
300
400
500
600
LINE LENGTH—MILES
(NO SERIES OR SHUNT COMPENSATION)

Constraints in a transmission system

In theory, a transmission system can carry power up to its thermal loading limits.

But in practice, to reach the thermal limit, the system has to satisfy the following constraints:

- Transmission stability limits
- Voltage limits
- Loop flows

Power transfer limits

By definition, the main limiting factor in a transmission system is the thermal limit.

If this is exceeded, the transmission line, due to the heat generated by the line current, sags will increase resulting in reduced clearances and would be unsafe.

If the system is operated close to its thermal limit, it is being used to its maximum capacity.

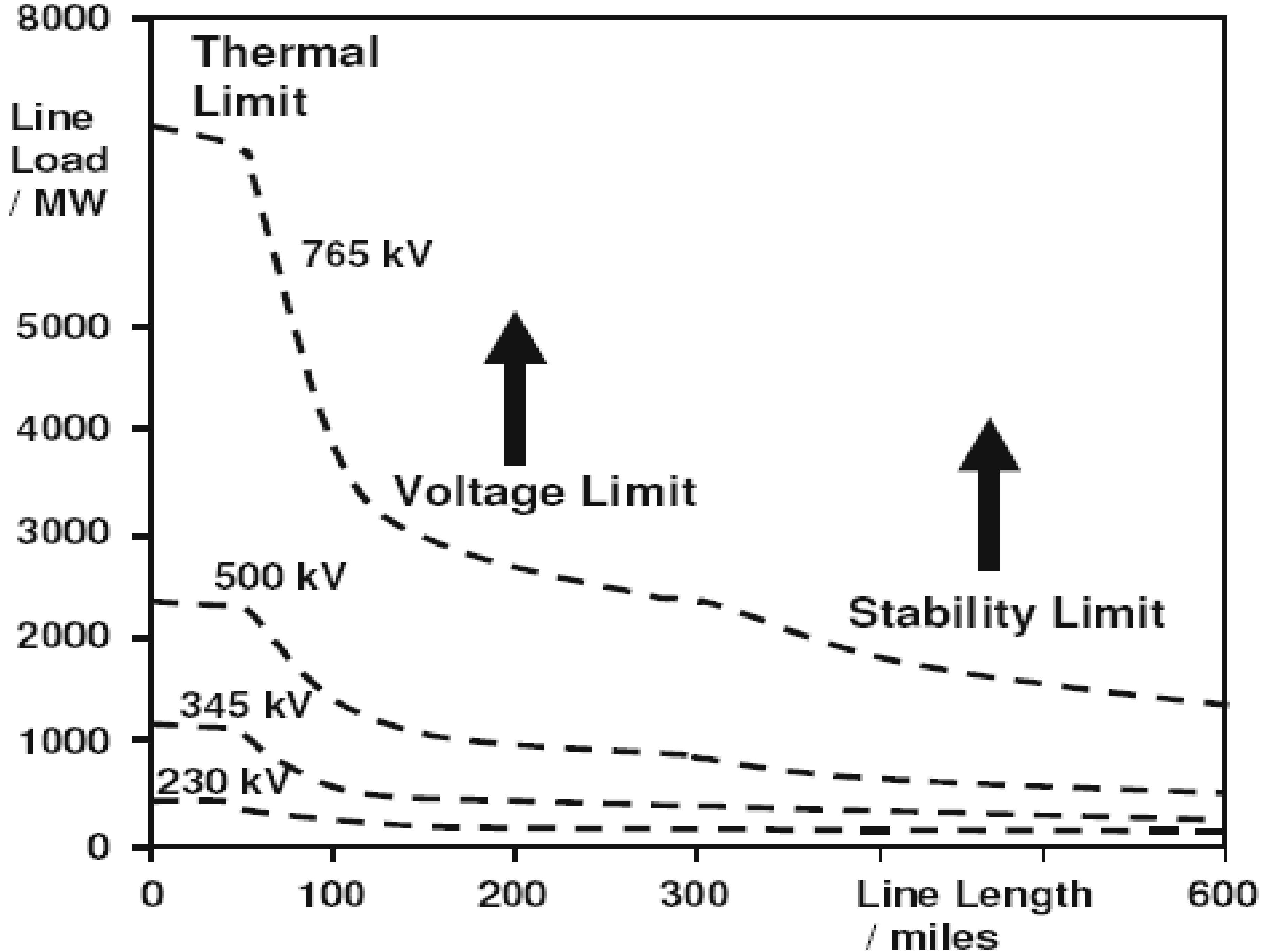
However, the thermal limit is hardly achieved since voltage or stability limits restrict the capacity of a transmission system

Power transfer limits..

Voltage limits normally require that the voltage level within a transmission system be maintained within a specified interval, for instance ±5 percent of the nominal voltage.

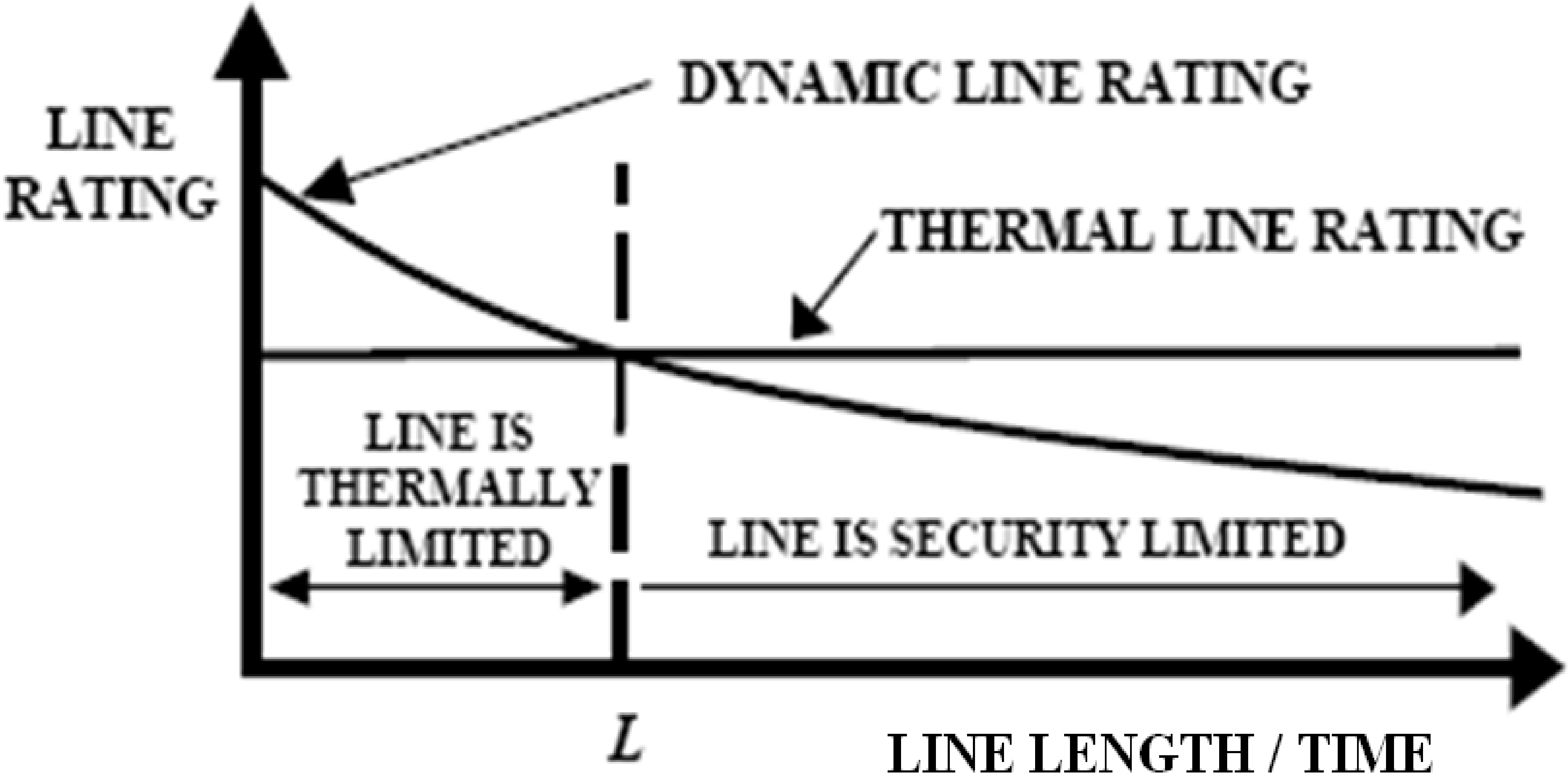
Stability limit – rapid and slow phenomena.

- **Transient** (or angular) stability refers to rapid events, for instance, the reaction of the voltage to faults in the transmission system caused by events such as lightning or sudden disturbance.
- **Dynamic** stability refers to slower events, for instance, power oscillations occurring from disconnection of large amounts of generation or load, or switching of some lines.



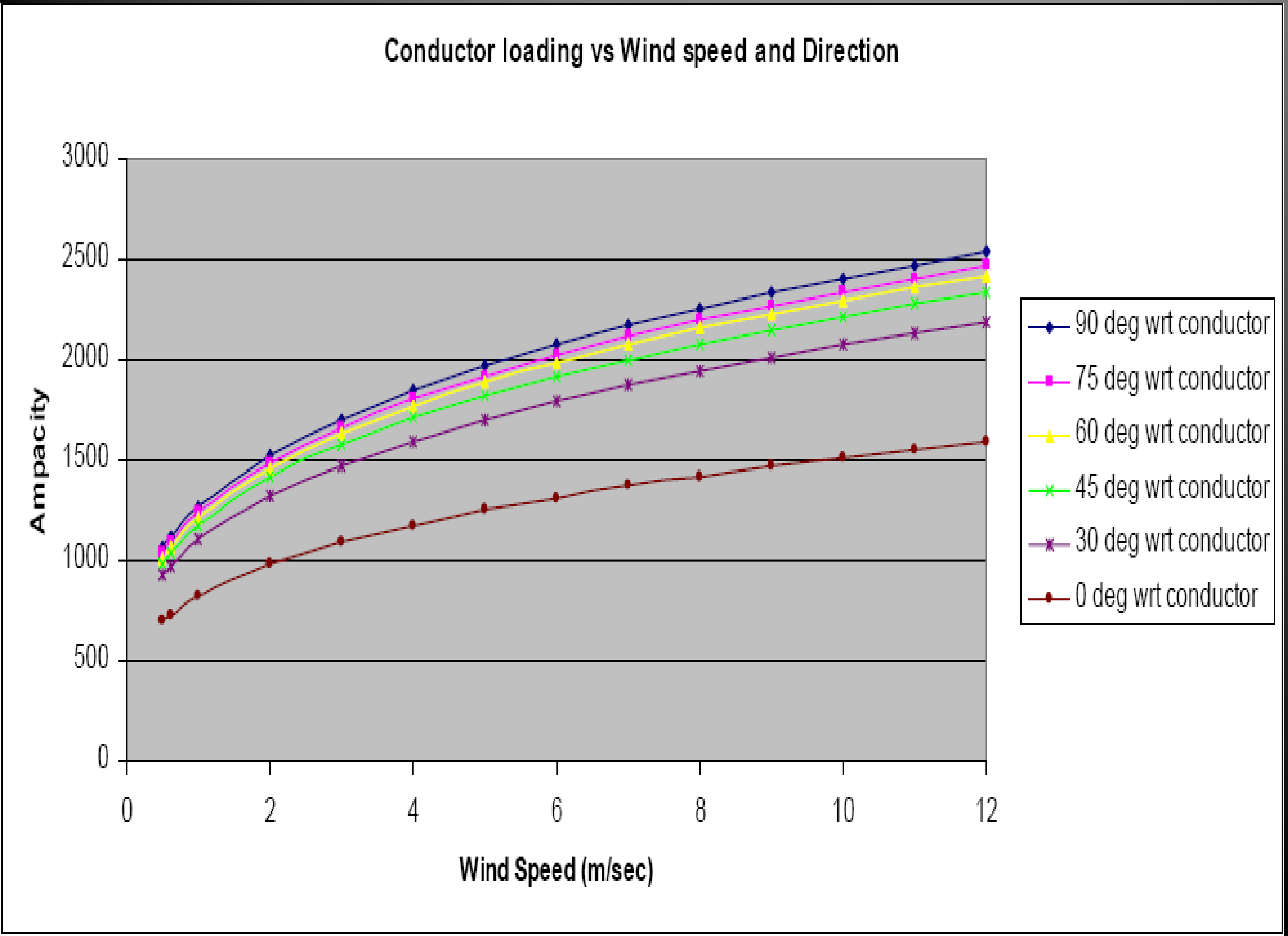
8000
5000
4000
3000
2000
1000
0
Line
Load
/ MW
Thermal
Limit
765 kV
500 kV
345 kV
230 kV
Voltage Limit
Stability Limit
0
100
200
300
Line Length
/ miles
600

Dynamic & Thermal Rating of OH Line

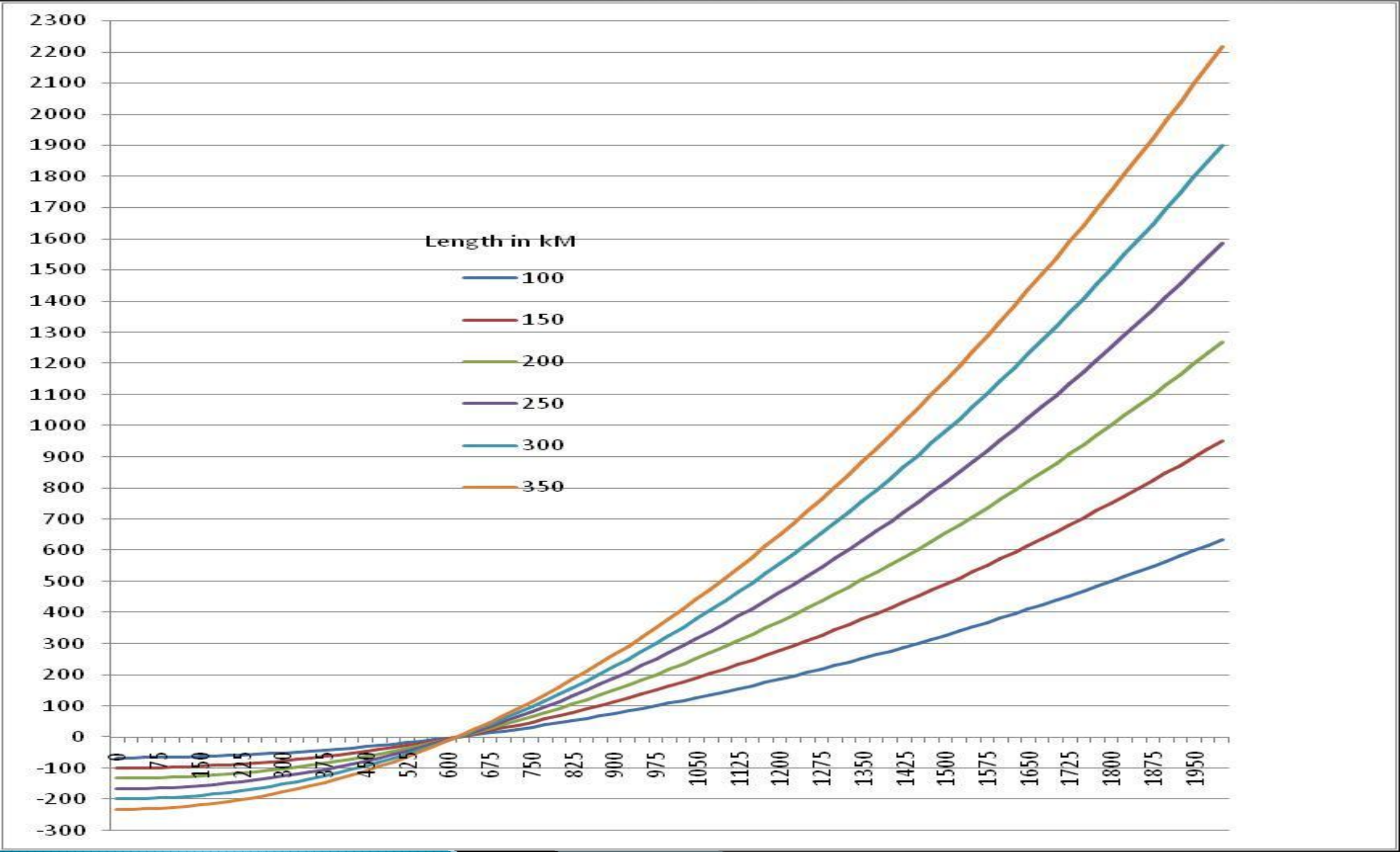


The thermal rating of the line

- Ambient temperature
- Wind velocity
- Age of the conductor
- Type of construction


Conductor loading vs Wind speed and Direction
Ampacity
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
Wind Speed (m/sec)
90 deg wrt conductor
75 deg wrt conductor
60 deg wrt conductor
45 deg wrt conductor
30 deg wrt conductor
0 deg wrt conductor

Reactive Power Consumption



Network optimisation

- Phase shifting transformers to control active and reactive power flows
- Series capacitors or controlled series reactors to adjust the impedances of network branches, and
- FACTS elements (including DC links) to control voltage, active or reactive power flows

International Experiences

Power Flow control in NGC

NGCs broad approach to planning the future development of the transmission system has been to try to maximise the utilisation of the existing system.

This has been achieved by the strategic deployment of power flow and reactive compensation devices.

To improve real power sharing 15 Quadrature Boosters or phase shifting transformers have been installed at both the 275 kV and the 400 kV voltage levels with ratings ranging from 750 MVA to 2750 MVA.

In order to maintain voltage profile, reactive power compesnation devices are installed at 400kV, 275kV and 132kV.

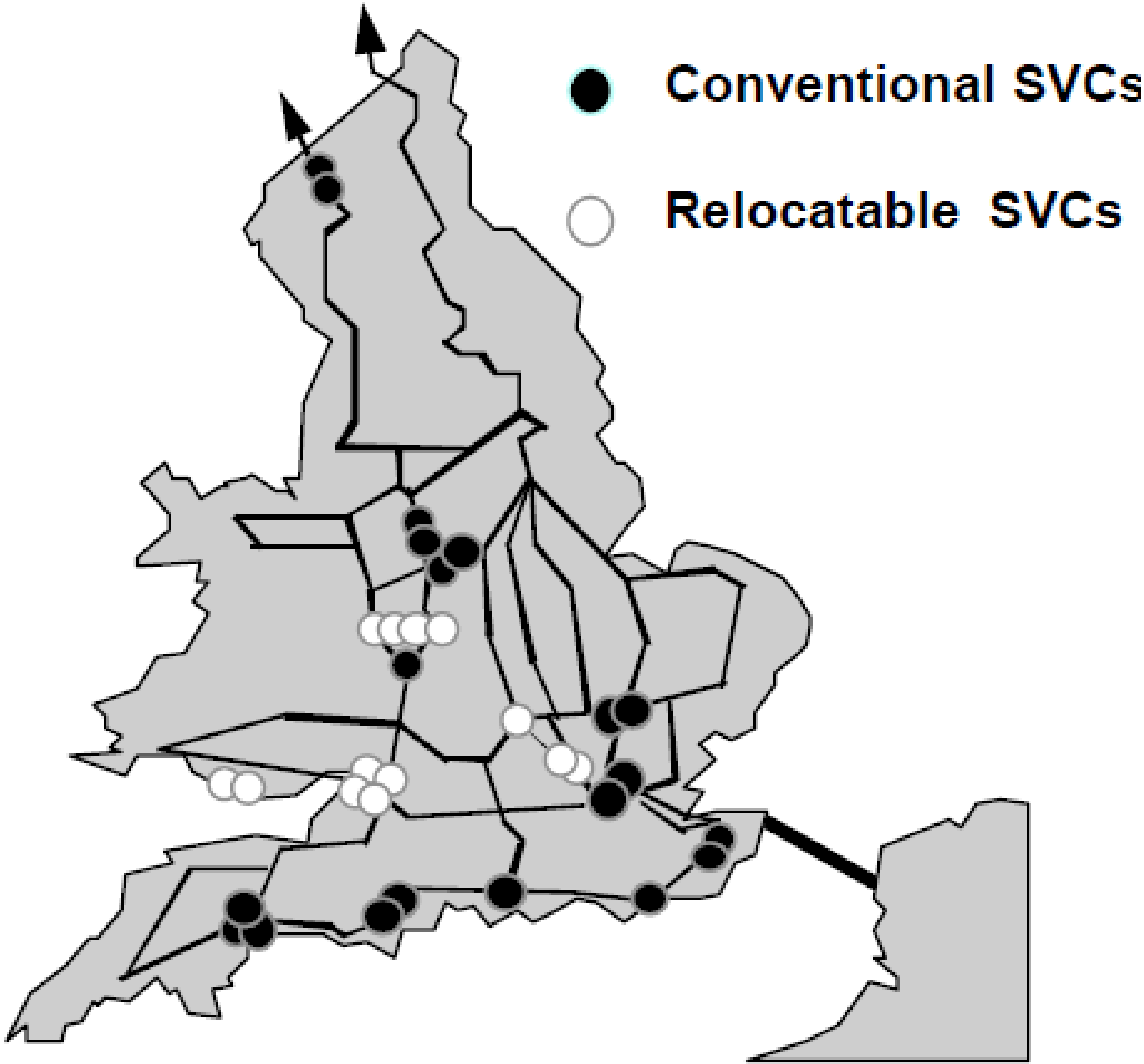
RPC in NGC

Voltage kV	Type	Number	Total-Capacitive	Total-Inductive
66	MSC	2	120	
132	MSC	105	5889	
132	MSR	71		4170
275	MSC	14	2100	
275	MSR			2080
275	SVC	6	900	512
275	Statcom	5	240	150
400	MSC	30	6750	
400	MSR	12		2400
400	SVC	14	2100	1275
400	Statcom	3	180	90
	SVC Teritiary	12	720	
	Total		18999	10677

Re-locatable SVC

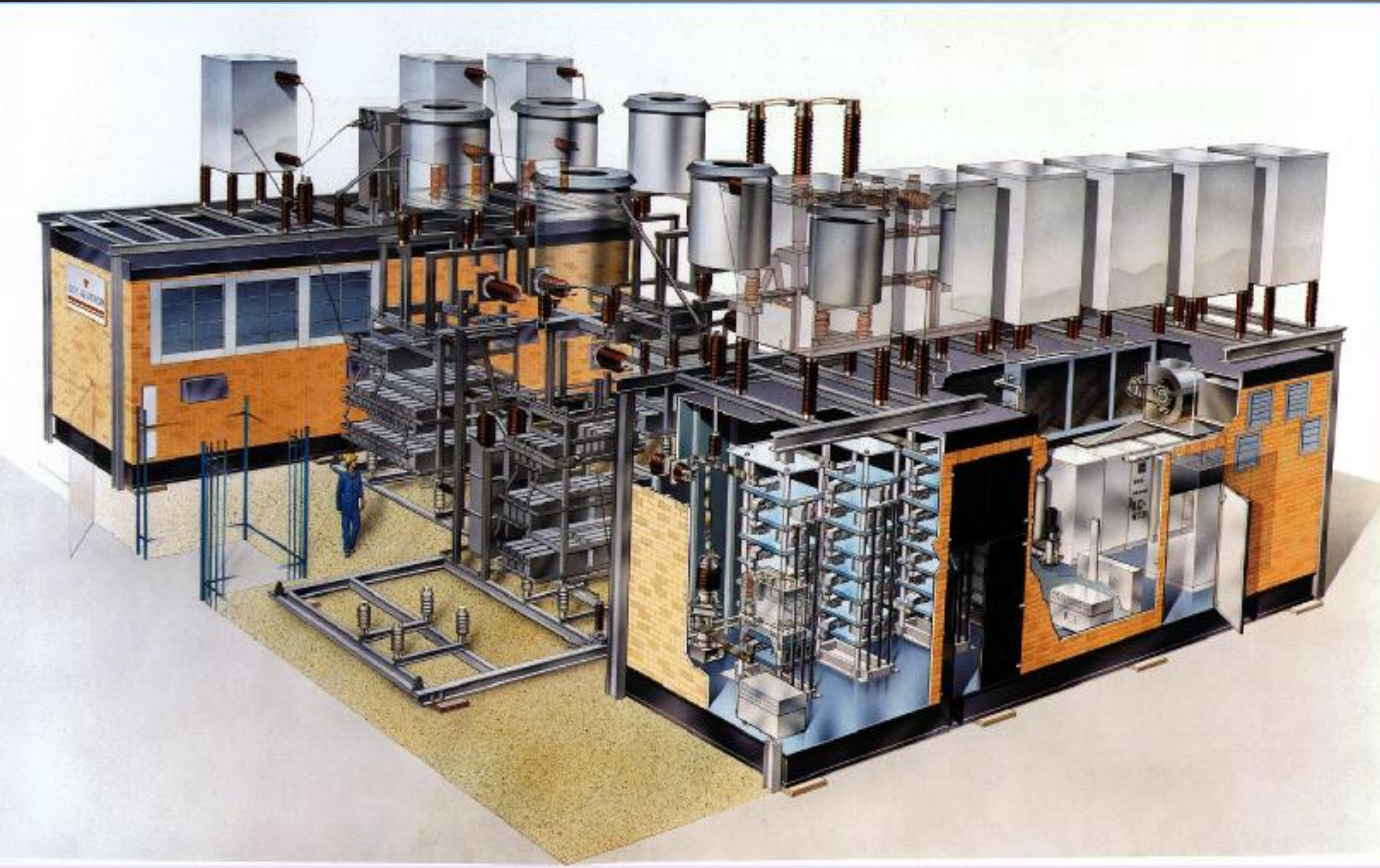
In order to take care of system planning uncertainties faced by National Grid, relocatable reactive compensation systems are installed with enhanced system performance.

To date, 12 relocatable SVCs (RSVCs) have been installed as part of a planned program of work to meet these changing system needs.



Conventional SVCs
Relocatable SVCs

Re-locatable SVC



Re-locatable SVC

Phase shifting Transformer

Phase-shifting transformers (PST) have been around for more than 60 years.

They are typically used for increasing or decreasing transmission line power flow.

For instance, PSTs often compensate for undesirable phase angle differences at given line terminals resulting from highly variable power generation dispatch within a network or between networks.

Phase shifting Transformer

Many TSO's prefer phase shifting transformer or Quad Boosters to control power flow

Phase shifting transformers have been developed for transmission system enhancement in steady state system conditions.

The operation principle is voltage source injection into the line by a series connected transformer, which is fed by a tapped shunt transformer

Speed of phase shifting transformers for changing the phase angle of the injected voltage via the taps is very slow: typically between 5 and 10 s per tap, which sums up for 1 minute or more, depending on the number of taps

Phase shifting Transformer in NGC

In NGC over 15 phase shifting transformers are in operation with 6Nos. at 275kV, 750MVA capacity and 9nos. at 400kV, 2000MVA to 2750MVA capacity

These are installed in North south and East west corridors to relieve congestion during system operation.

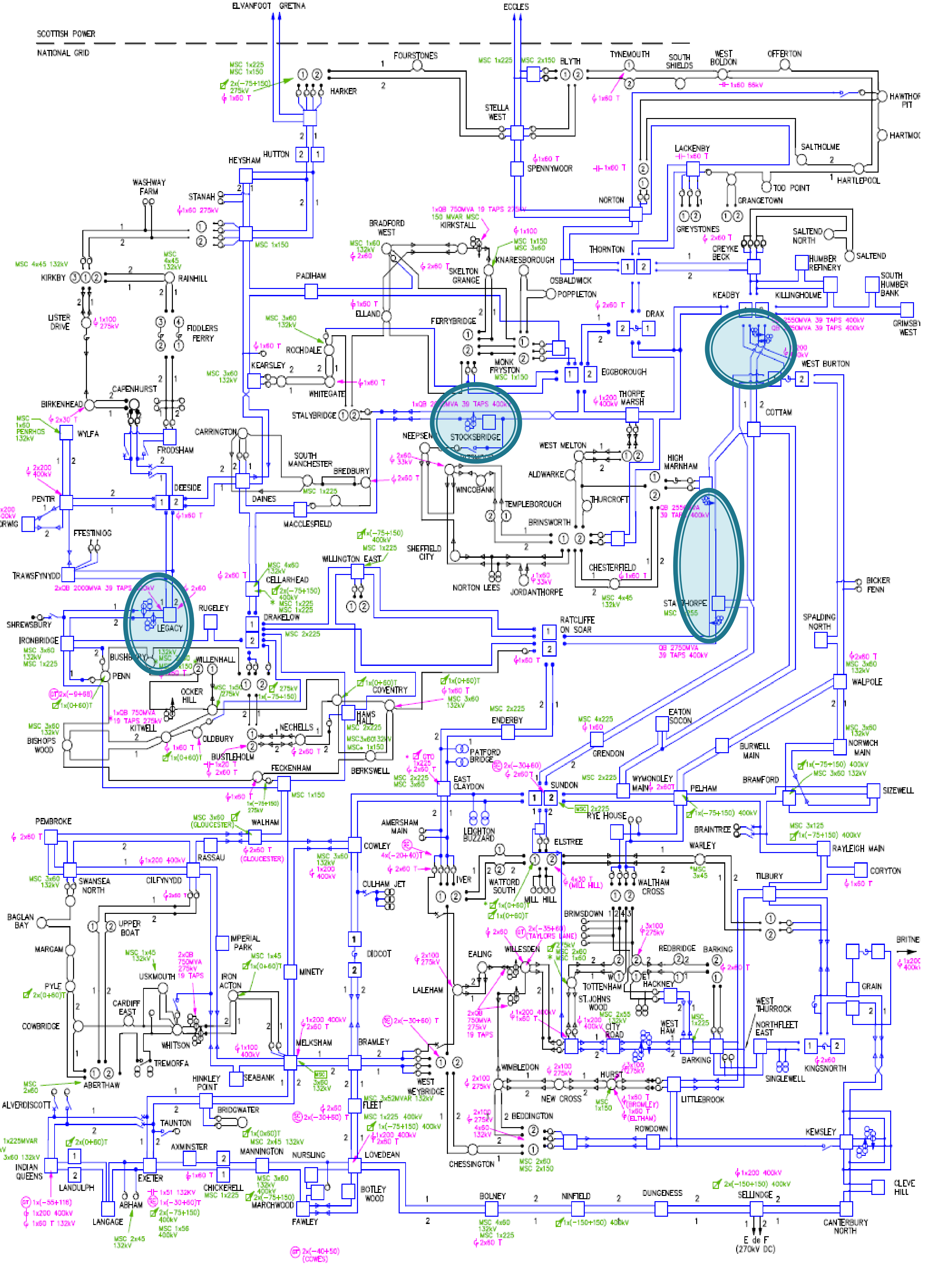
Phase shifting Transformer in UCTE

In the context of the open market the phase shifter is an important device in the energy transport in the UCTE power system

In the German 380 kV bulk power system a 1500 MVA phase shifter is in operation since about 15 years.

The main driving force for the installation was the energy exchange of about 1000 MW between the western part of the German grid and mainly the southern part and also the northern part.

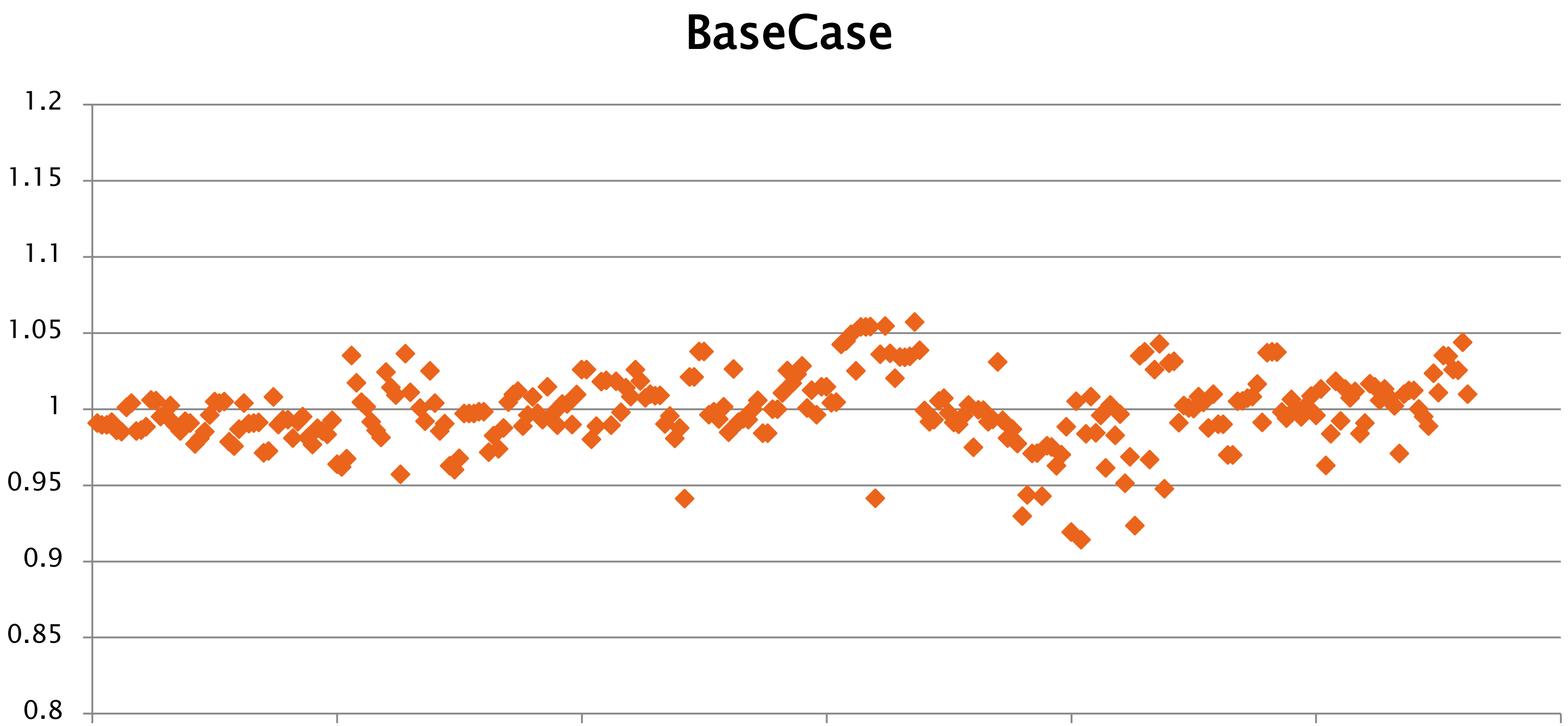
The decision for the phase shifter solution was made on the basis of lower costs.



SCOTTISH POWER
NATIONAL GRID
ELVANFOOT
GRETNA
ECCLES
FOURSTONES
HARKER
BLYTH
TYNEMOUTH
SOUTH SHIELDS
WEST BOLDON
OFFERTON
STELLA WEST
HUTTON
HEYSHAM
SPENNYMOOR
LACKENBY
SALTHOLME
HARTLEPOOL
TOD POINT
GRANGETOWN
NORTON
GREYSTONES
THORNTON
CREYKE BECK
SALTEND NORTH
SALTEND
HUMBER REFINERY
SOUTH HUMBER BANK
KILLINGHOLME
KEADBY
GRIMSBY WEST
WEST BURTON
COTTAM
DRAX
EGGBOROUGH
THORPE MARSH
WASHWAY FARM
STANAH
KIRKBY
RAINHILL
LISTER DRIVE
FIDDLERS FERRY
PADIHAM
BRADFORD WEST
KIRKSTALL
KNARESBOROUGH
SKELTON GRANGE
OSBALDWICK
POPPLETON
ELLAND
FERRYBRIDGE
MONK FRYSTON
ROCHDALE
KEARSLEY
WHITEGATE
CAPENHURST
BIRKENHEAD
WYLFA
STALYBRIDGE
STOCKSBRIDGE
NEEPSEND
WEST MELTON
HIGH MARNHAM
ALDWARKE
CARRINGTON
FRODSHAM
SOUTH MANCHESTER
BREDBURY
DEESIDE
DAINES
WINCOBANK
TEMPLEBOROUGH
THURCROFT
BRINSWORTH
PENTIR
MACCLESFIELD
FFESTINIOG
SHEFFIELD CITY
WILLINGTON EAST
CHESTERFIELD
TRAWSFYNYDD
CELLARHEAD
NORTON LEES
JORDANTHORPE
BICKER FENN
LEGACY
RUGELEY
DRAKELOW
RATCLIFFE ON SOAR
STAYTHORPE
SHREWSBURY
IRONBRIDGE
SPALDING NORTH
BUSHBURY
WILLENHALL
PENN
WALPOLE
OCKER HILL
COVENTRY
HAMS HALL
KITWELL
ENDERBY
EATON SOCON
BISHOPS WOOD
OLDBURY
NECHELLS
GRENDON
BURWELL MAIN
NORWICH MAIN
BUSTLEHOLM
PATFORD BRIDGE
FECKENHAM
BERKSWELL
EAST CLAYDON
SUNDON
WYMONDLEY MAIN
PELHAM
BRAMFORD
SIZEWELL
PEMBROKE
RYE HOUSE
WALHAM
AMERSHAM MAIN
LEIGHTON BUZZARD
BRAINTREE
RASSAU
COWLEY
ELSTREE
WARLEY
RAYLEIGH MAIN
SWANSEA NORTH
CILFYNYDD
CULHAM JET
IVER
WATFORD SOUTH
MILL HILL
WALTHAM CROSS
TILBURY
CORYTON
BAGLAN BAY
UPPER BOAT
BRIMSDOWN
MARGAM
IMPERIAL PARK
DIDCOT
EALING
WILLESDEN
REDBRIDGE
BARKING
BRITNED
PYLE
USKMOUTH
IRON ACTON
MINETY
LALEHAM
TOTTENHAM
HACKNEY
GRAIN
CARDIFF EAST
ST.JOHNS WOOD
CITY ROAD
WEST HAM
WEST THURROCK
NORTHFLEET EAST
COWBRIDGE
WHITSON
MELKSHAM
BRAMLEY
TREMORFA
ABERTHAW
HINKLEY POINT
SEABANK
WEST WEYBRIDGE
WIMBLEDON
HURST
SINGLEWELL
KINGSNORTH
NEW CROSS
LITTLEBROOK
ALVERDISCOTT
BRIDGWATER
FLEET
BEDDINGTON
ROWDOWN
KEMSLEY
TAUNTON
AXMINSTER
MANNINGTON
NURSLING
LOVEDEAN
CHESSINGTON
INDIAN QUEENS
EXETER
LANDULPH
CHICKERELL
MARCHWOOD
BOTLEY WOOD
BOLNEY
NINFIELD
DUNGENESS
SELLINDGE
CLEVE HILL
ABHAM
LANGAGE
FAWLEY
CANTERBURY NORTH
E de F (270kV DC)

Indian Context

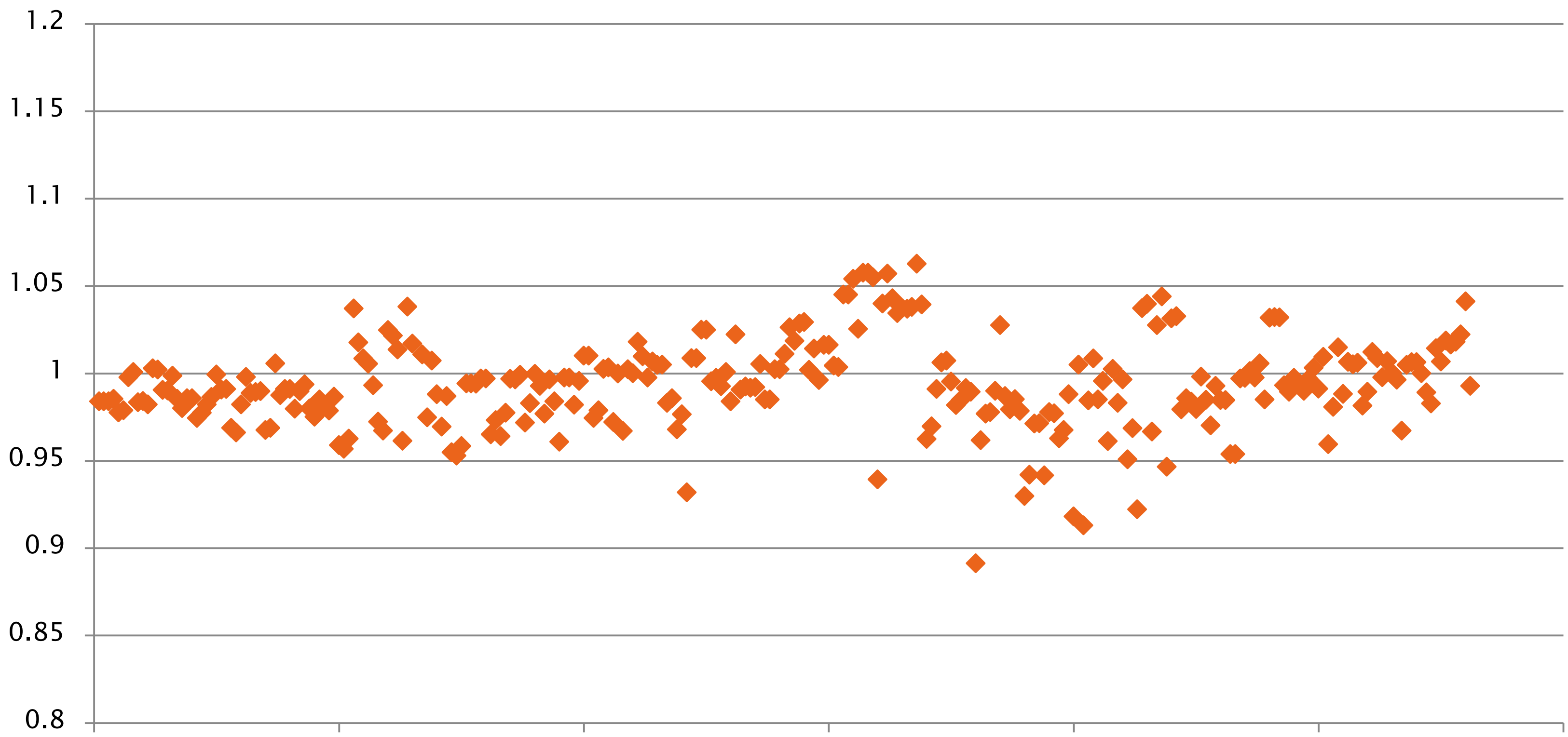
Voltage profile observed in New grid



Inter-Regional Lines tripped (Nr-Wr region)- except Agra - Gwalior Line

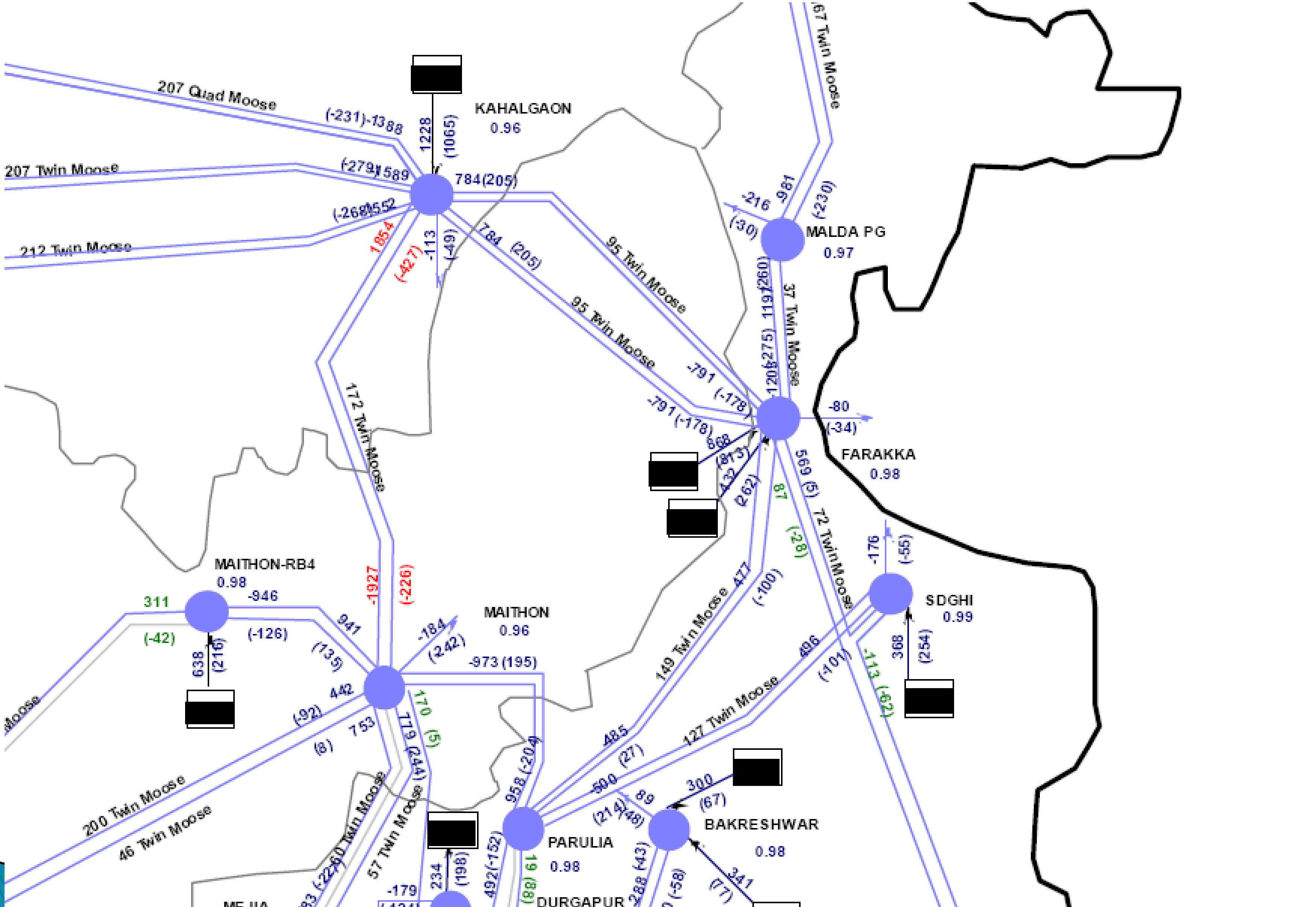
Voltage profile observed in New grid

Case 1- Disturbance condition (outage of inter-regional lines[NR to WR]+ Agra-Gwalior link still in service)

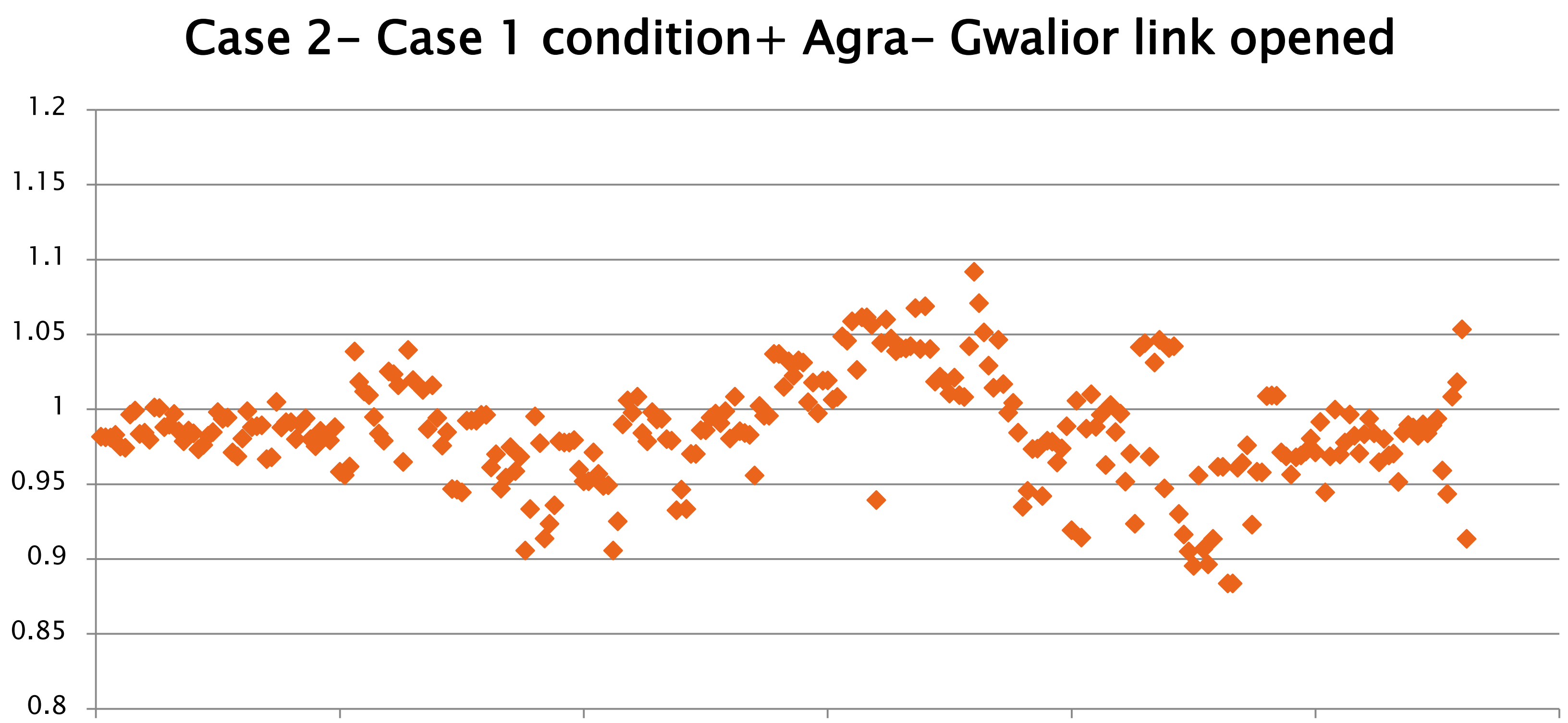


- Inter-Regional Lines tripped (Nr-Wr region)

Geographical map around Parulia – without Phase shifting transformer

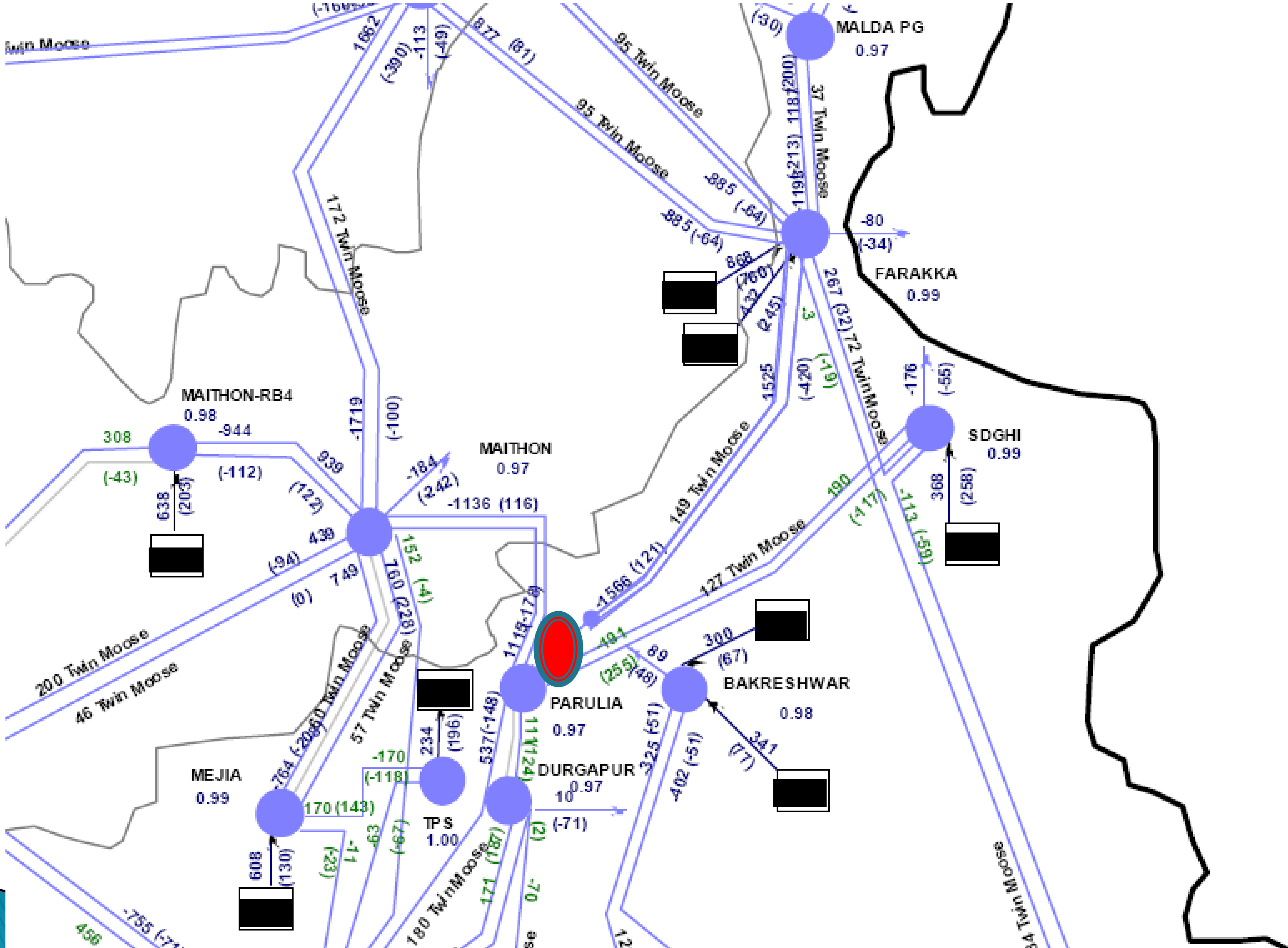


Voltage profile observed in New grid

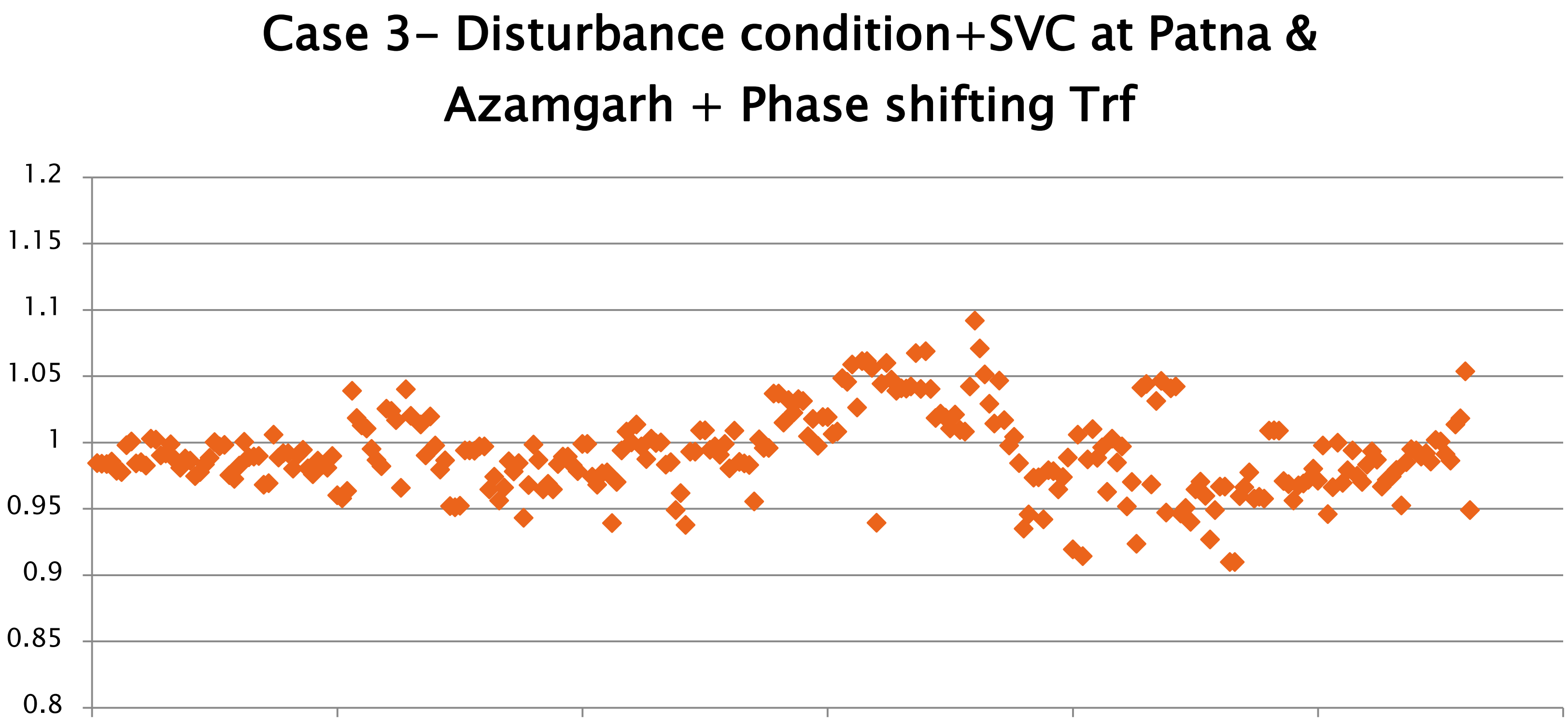


- Inter-Regional Lines tripped (Nr-Wr region)
- SVC at Patna & Azamgarah S/S
- Phase shifting transformer at Purnia to Farakka

Geographical map around Parulia – with Phase shifting transformer

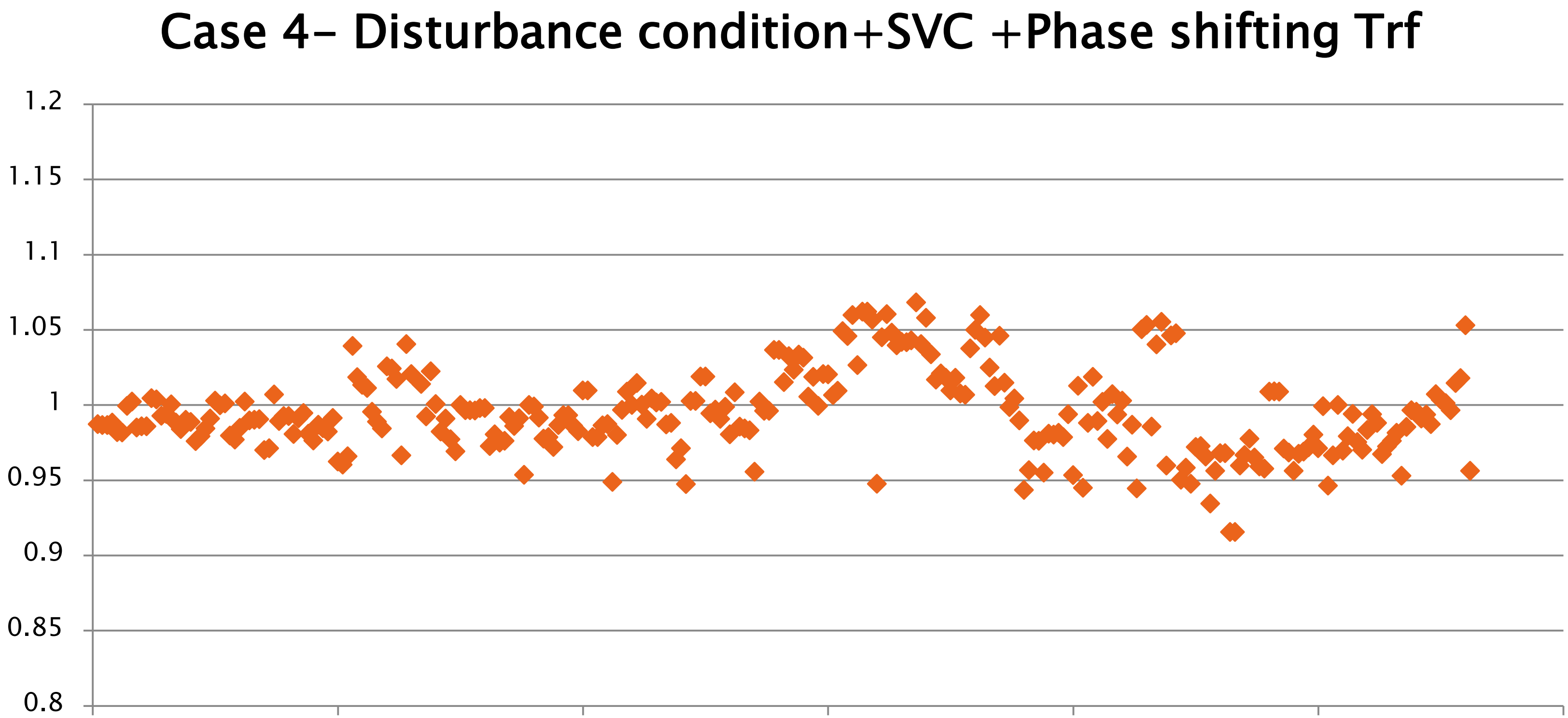


Voltage profile observed in New grid



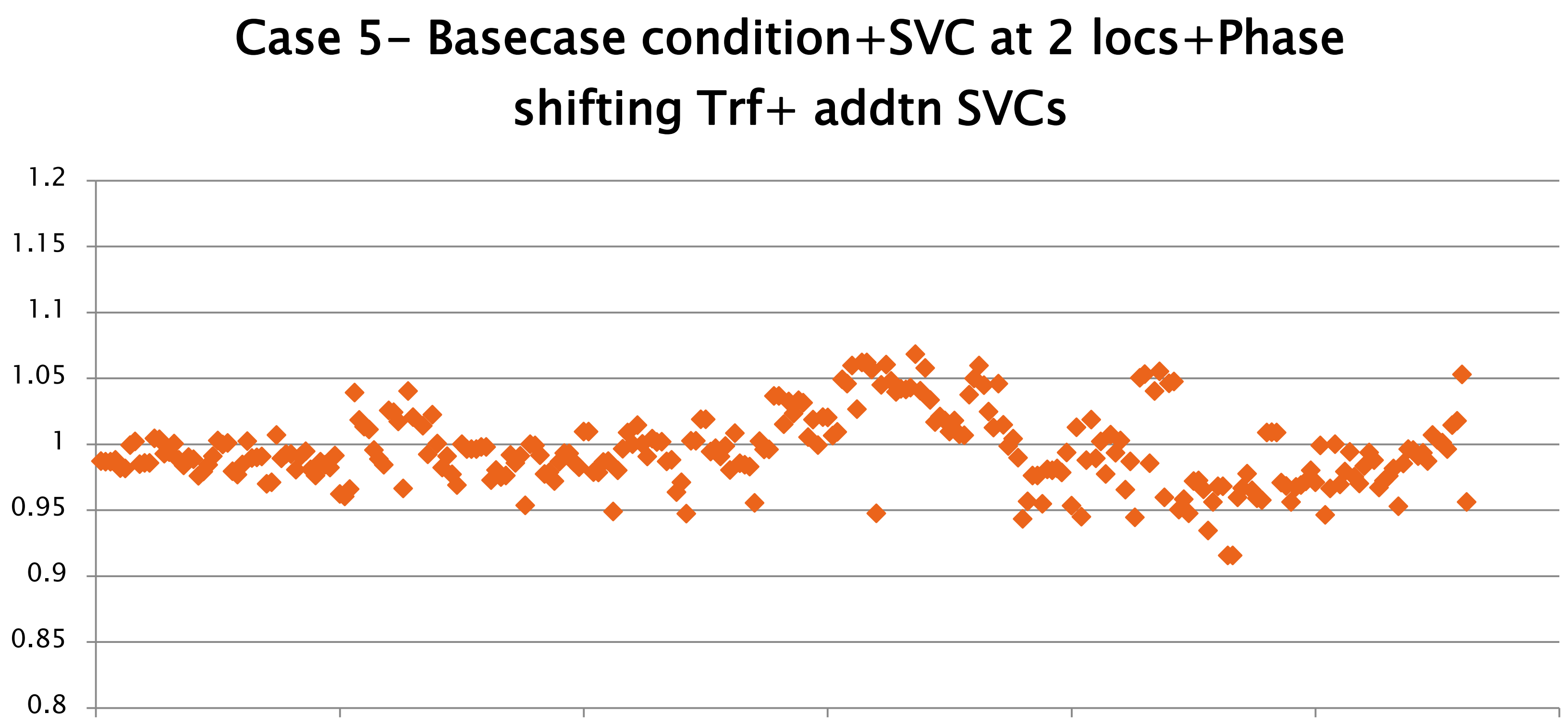
- Inter-Regional Lines tripped (Nr-Wr region)
- SVC at Patna, Azamgarah, Kalwa, Sultanpur, Kashipur, Gwalior S/S
- Phase shifting transformer at Purnia to Farakka

Voltage profile observed in New grid

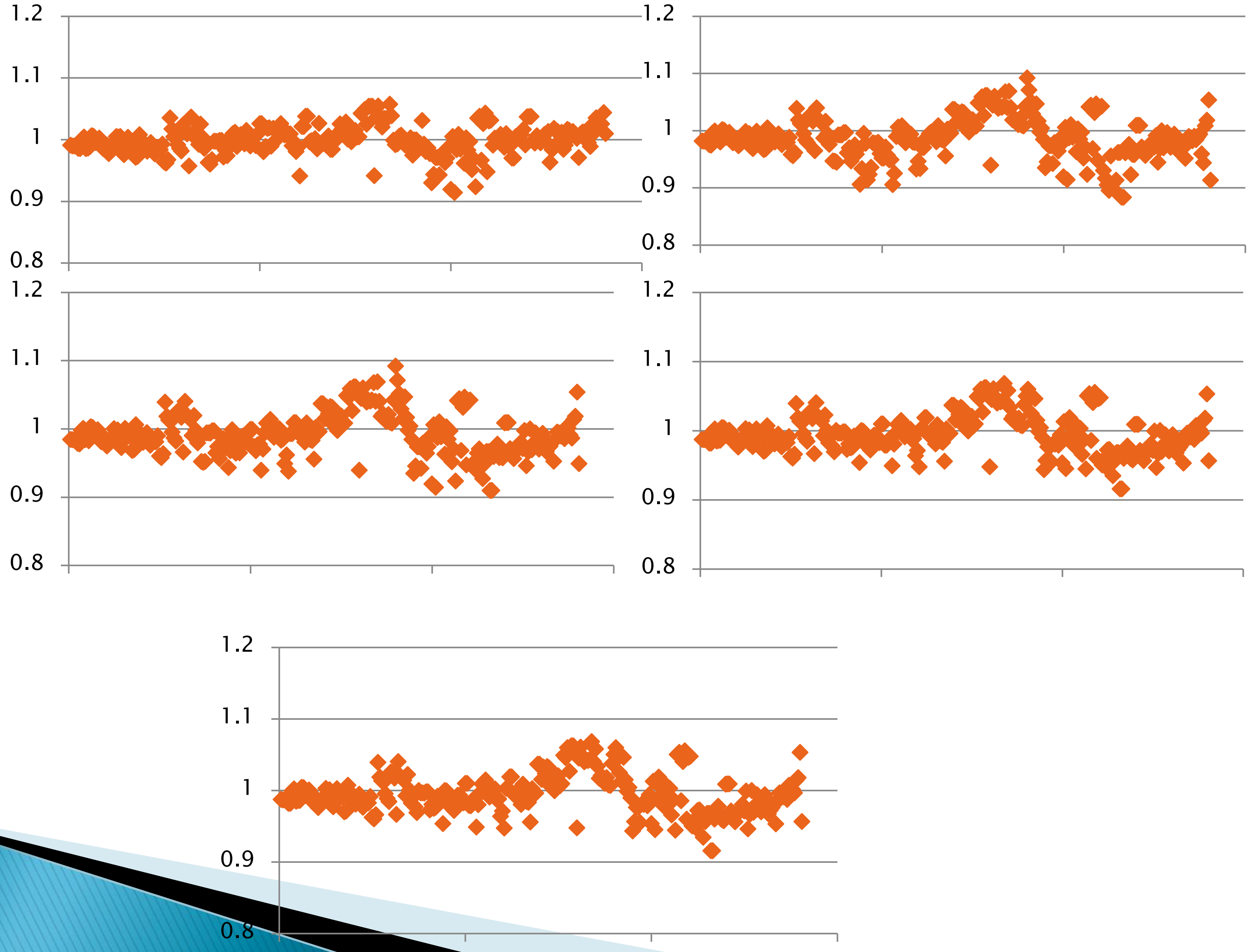


- Inter-Regional Lines are in service (Nr-Wr region)- similar to Basecase
- SVC at Patna, Azamgarah, Kalwa, Sultanpur, Kashipur, & Gwalior S/S
- Phase shifting transformer at Purnia to Farakka

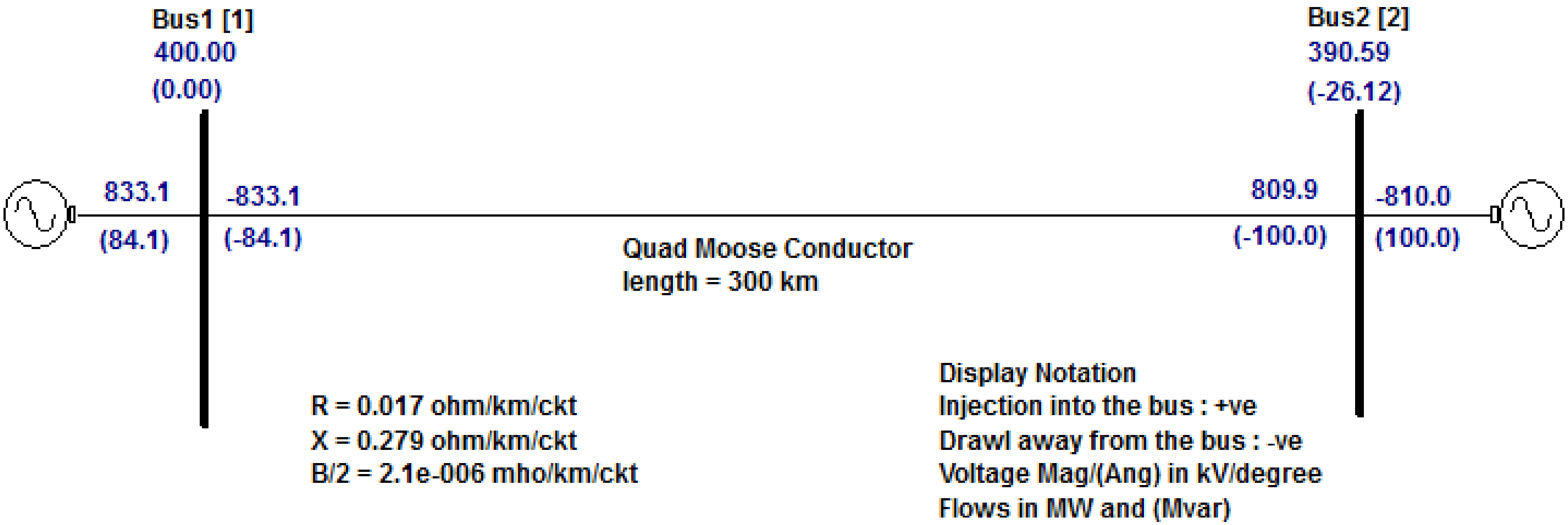
Voltage profile observed in New grid



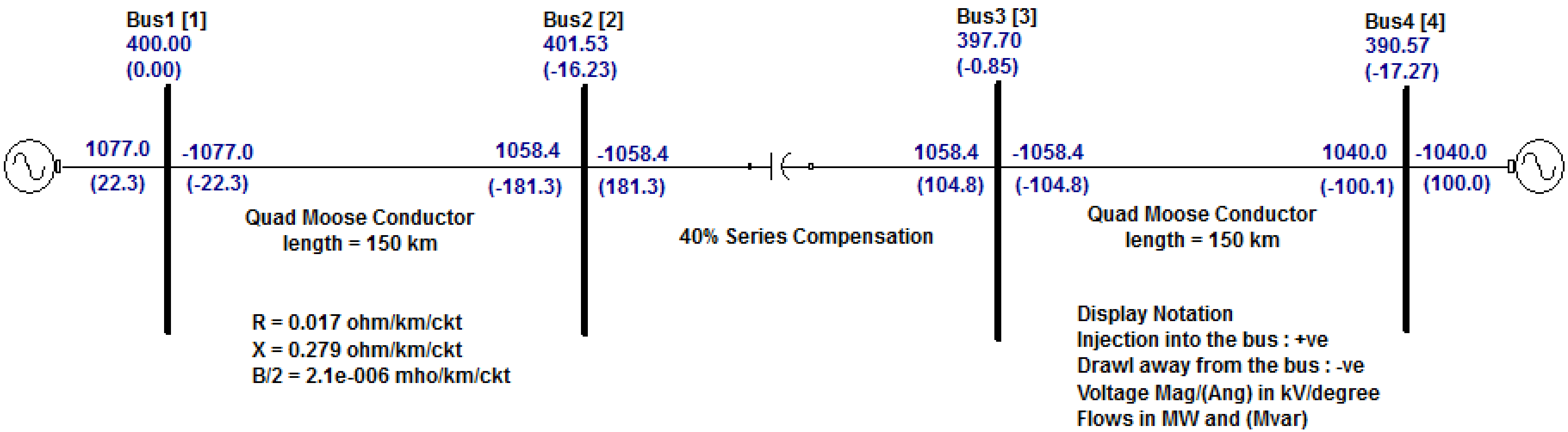
Voltage profile observed in New grid



Economics of Dynamic compensation

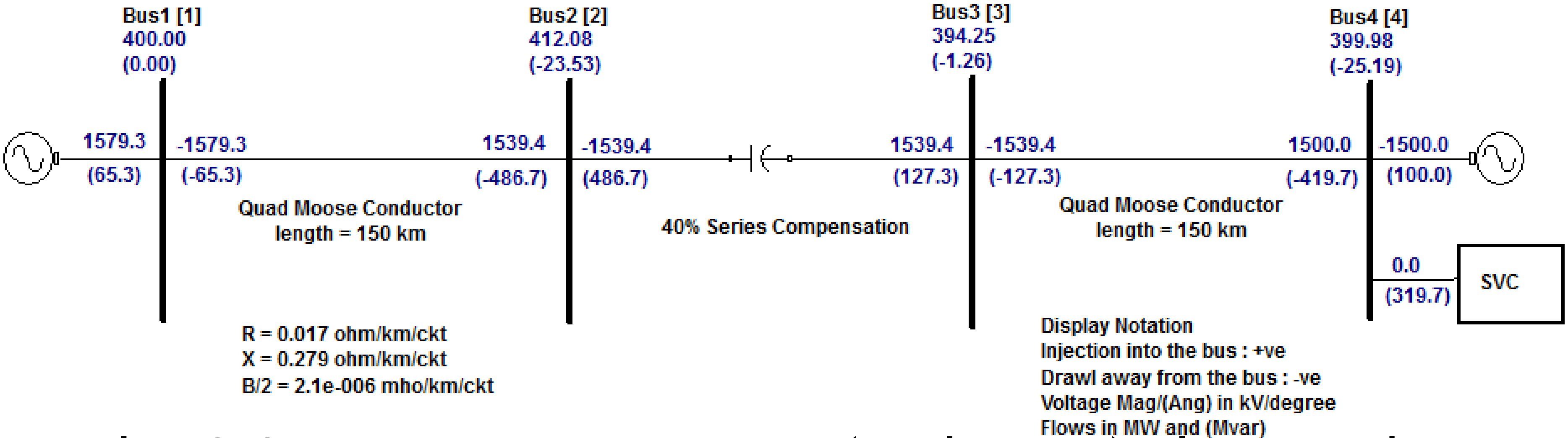


Maximum Power Transfer on a 300kM 400kV Quad line is 800MW.
Cost/km = Rs.1.8Crores
Investment Cost/MW = Rs.0.675Crores



With 40% series compensation (mid point) power transfer can increase to 1040MW – an increase of 240MW – Investment around Rs.40Crores

Investment Cost/MW = Rs.0.5645Crores



With 40% series compensation (mid point) along with +400/-100MVAr SVC power transfer can increase to 1500MW – an increase of 700MW

Additional Cost – Rs.80Cr (app.)

Investment Cost/MW = Rs.0.4439Crores

Conclusion

The main challenges for Large Open Access Systems is handling bottlenecks in the system, created by a mismatch between the desire of the marketplace and the transmission system physical capability

PST & FACTS devices provide Open Access systems with flow- and stability control functionality, and are as such one of several options for increasing the systems physical capacity.

Advantage over transmission line expansion and traditional flow control units is that they are more robust with respect to varying flow patterns.

But they do not really increase capacity, they only enable the utilisation of the systems maximum capacity.

Discussion

Thank you

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