Special Protection Schemes for Eastern regional Grid of India- A Case Study

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Abstract
With integration of IPPs into the National grid, increase in short term open access transactions including power exchange transactions and consequent congestion in several corridors, manual actions would be inadequate to ensure grid security. Automation would enhance grid security as time is crucial in real time operation. The Special Protection Schemes (SPS) are stepping stones to introduction of Smart Grid Technology. Eastern Regional Load Despatch Centre (ERLDC) of India had already taken initiative for Smart Grid by way of proposed introduction of synchrophasor technology. System Protection Schemes (SPS) have been planned in Eastern Region to relieve the flowgate congestion and to ensure n-1 compliance in some important corridors during export. Other key drivers are to enable operation of inter-regional and intra-regional corridors closer to limits to facilitate efficient Market operation and avoid market splitting. This paper discusses in detail the issues of flowgate congestion in some corridors of Eastern Region of India. The paper also describes Special Protection Schemes (SPS) devised by ERLDC and slated for implementation in Eastern Region. The initiative to implementation of SPS in Eastern Region would also help in harnessing some applications later through the proposed synchrophasor technology project.

I. Introduction

Smart Grid initiatives include smart metering, synchrophasor technology, etc. and have been widely discussed for implementation. However, many of these projects are implemented as pilot projects and power system applications using the PMU data are yet to be harnessed. Introduction of Special Protection Schemes (SPS) would be the first step towards Smart Grid initiatives to relieve congestion in flowgates, and to operate various transmission corridors closer to limits to enable efficient market operation. Ensuring security of the grid in case of non-compliance of n-1 criterion in certain corridors through automations rather than manual actions is one of the key drivers for SPS. Some of the applications of SPS widely implemented include the following:-

- Generation Rejection
- Turbine fast valving / generator run-back
- Gas turbine / Pumping storage start-up
- Under frequency load shedding
- HVDC fast power change
- Automatic shut reactor / capacitor switching
- Controlled disconnection of inter-connection / area islanding
- Tap changer blocking and set point adjustment
- Quick increase of generator voltage set point
- Dynamic braking or braking resistor
- Actions on the AGC such as set point changes.

Special Protection Schemes (SPS) provide automatic action to relieve impact of contingencies and enhance grid security. The Special Protection Schemes are normally sleeping systems which operate infrequently. The control actions taken by SPS are pre-determined and the scheme can be armed or disarmed depending on system condition. Further, SPS provides number of actions in coordinated manner and can also be applied with actions system wide by using faster communication facilities. Similarly, the SPS can be actuated by accessing information from several locations and as such can be characterized as Wide Area Protection Schemes. These characteristics qualify the SPS to be among the Smart Grid initiatives. In certain complex SPS schemes, two-way communication as well as communication between multiple SPS can also be introduced.

In the Indian context, an SPS scheme, for tripping of units / ramping down of generation of Talcher Stage – II power station as well as another SPS for shedding of loads through Southern Region in the event of tripping of one or both the poles of Talcher – Kolar HVDC bi-pole, are already in service [1] and functioning successfully as per the designed criteria.

Eastern Region being connected to all other regions in the country as well as having international connections with Bhutan and Nepal, it is crucial for ER grid to be reliable and secure for wheeling of power taking place in multiple directions. In case any three regions in the country happens to be

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surplus and one region happens to be deficit, several transmission corridors in all the regions are likely to be congested due to transfer of power and may require some automatic actions. Another important consideration for introduction of SPS in ER is to relieve the flowgate congestion (discussed in section III) and to enhance the Total Transfer Capability (TTC) / Available Transfer Capability (ATC) across intra and inter-regional corridors. In certain corridors, due to lack of n-1 compliance, critical loading due to contingency can only be relieved through automatic action to reduce risk of a disturbance. This makes the SPS an absolute necessity. Accordingly, several Special Protection Schemes have been planned in Eastern Region viz.

- SPS for 400 kV Farakka – Kahalgaon D/C
- SPS for 400 kV Farakka – Malda D/C
- SPS for 400 kV Binaguri – Purnea Q/C
- SPS for 400 kV Purnea - Muzaffarpur D/C
- SPS for Starlite Energy Ltd. IPP
- SPS for Mejia ‘B’ power station and Maithon Power Ltd. IPP

Only three Special Protection Schemes have been described in detail while the other three Special Protection Schemes have been discussed in brief in the ensuing sections.

II. Overview of ER Grid

The Indian power system is operating as two large grids connected in asynchronous mode viz. N-E-W grid comprising Northern (NR), Eastern(ER), Western (WR) and North Eastern (NER) regions as one synchronously interconnected system and the Southern grid (SR) connected to the NEW grid asynchronously through HVDC links. The NEW grid has an installed capacity of 116348 MW and is presently meeting peak demand of around 80000 MW. The Southern grid is having installed capacity of 44220 MW and meeting peak demand of around 24000 MW. The formation of NEW grid immensely helped all the four regions synchronously connected, through sharing of scarce generation resources, diversity of peak demands, improvement in hydro thermal mix and increase of system stiffness (1800-2000MW per Hz). The Eastern Regional Grid comprises the states of West Bengal, Orissa, Bihar, Jharkhand and Sikkim. The installed capacity of Eastern region is 23119 MW (including Talcher STPS Stg-II) and peak demand met is of the order of 13000 MW and above. The energy consumption is around 260 MU per day and daily net export from Eastern region is around 40 MU.Eastern Regional Load Despatch Center [ERLDC] has been designated, as the apex body in grid operation to ensure secure and economic operation of the Eastern Regional power system. As such the EHV grid of Eastern Region is being operated under the supervision and control of ERLDC on round the clock basis.

CERC has granted permission to set up power exchanges in India to ensure market-driven economy and price discovery where prices are decided by the forces of demand and supply. These forces are contradictory: e.g., the seller wants high prices while the buyer wants low prices. These conflicting forces determine the correct price and volume of a commodity at a given time in a market-driven economy (Hourly bidding)**.** Presently two Power Exchanges viz. Indian Energy Exchange (IEX) and Power Exchange India Limited (PXIL) are in operation**.** Also another Power Exchange is likely to come up very shortly.

Eastern Region being strategically located, it is connected to all the other regions. The typical generation dispatch pattern and demand scenarios within the region as well as of the other regions during monsoon and winter, results in congestion in some corridors of the NEW grid and SR grid. As a result power market gets split in two parts where Market Clearing Price (MCP) and Market Clearing Volume (MCV) are different for different parts. Special protection scheme (SPS) are designed in such a manner so that the congestion in the grid can be avoided, and at the same time security of the network maintained.

III. Operational Constraints in Flow Gates of ER Grid

Depending upon different seasons, demand and generation patterns vary leading to constraints in different corridors of the Eastern Grid

(i) Monsoon Flow Gate: - During full monsoon, the hydro power import from Bhutan, NER and generation of Teesta are essentially evacuated from Binaguri 400kV S/S shown in Fig.1. Northern Region having higher demand during this period, most of the hydro power amounting to more than 2000 MW, is evacuated to Northern Region along Tala Transmission System. The series compensated quad moose 400kV Purnea – Muzaffarpur D/C, because of its lower impedance, gets loaded at times beyond 1000 MW per circuit. Any outage of one of the circuits leads to very high loading of the other 400KV Purnea-Muzaffarpur circuit as well as the parallel 400kV Farakka-Kahalgaon D/C. Further trippings may lead to a major grid disturbance. Scenario may further deteriorate with the commissioning of Palatana (760MW) and Bongaigaon (750MW) in NER. Relying on manual actions to relieve line loadings could be catastrophic. Thus 400KV Purnea-Muzaffarpur D/C & 400 KV Farraka-Kahalgaon D/C constitute flow gate which is closely monitored and this flowgate limits the ATC of ER-NR corridor.

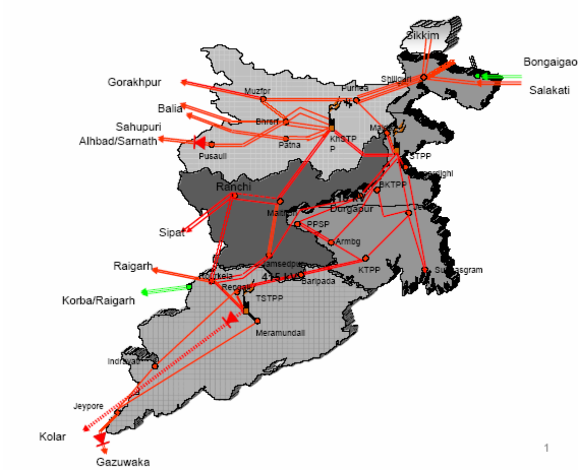

Fig.1

(ii) Winter: - The high demand in Northern Region during winter results in significant drawal from Eastern Grid. As hydro availability in North Eastern Region also gets depleted, overdrawal by NER is also a frequent phenomenon. The depleted hydro availability within Bhutan and Teesta cause surplus power available within the geographical territory of W. Bengal and Jharkhand to flow northwards along Farakka-Malda 400kV D/C to meet the requirement of NER , North Bengal and NR. Power flow through 400kV Farakka-Malda D/C frequently exceeds 1000MW, leading to congestion of this line. As the other 400kV path of Farakka-Kahalgaon D/C also remains heavily loaded, any outage of one circuit between Farakka and Malda or Farakka and Kahalgaon may lead to an emergency state. Thus 400 KV Farakka-Kahalgaon D/C and 400 kV Farakka-Malda D/C constitute the winter flow gate which limits the export (ER to NR) during winter.

A power map of Eastern Regional grid is available at www.erldc.org or www.erldc.com [2]

IV. A Case study of Market Split on 1st Dec 2009

For the purpose of scheduling collective transactions in Power Exchanges (Day-Ahead Market) India has been divided in ten different bidding areas A_1 A_2 (North Eastern Region), E_1 E_2 (Eastern Region), N_1, N_2 (Northern Region), S_1 S_2 (Southern Region) and W_1 W_2 (Western Region) shown in Fig 2. Temperature starts falling in the month of December and demand in Northern Region increases accordingly. Since it is winter season, the hydro support is not sufficient to meet this demand due to which constituents and utilities of NR purchase power through power exchanges and bilateral transactions. On 1st December 2009 the PX (Day-Ahead) market got split from 06:00 to 17:00 Hrs due to congestion between E1 (Bihar, Jharkhand and West Bengal) and N2 (Uttar Pradesh, Rajasthan and Delhi) bid areas. MCP and MCV for unconstrained and constrained markets for both Power Exchanges are shown in Table 1. MCP in N1, N2 is higher than that of E1, E2 bid areas. The calculation of undelivered power and congestion revenue (increased fuel cost/ cost of energy not served) are shown in Table 2 for IEX [3] and Table 3 for PXIL [4]. Due to market split total undelivered power was 8358 MWh and congestion revenue was Rs 2.69 Cr.

Table 1

	Un-Constrained Market		Constrained Market		
	MCP Rs/MWh	MCV MWh	MCP (Rs/MWh) N1,N2	MCP (Rs/MWh) E1,E2	MCV MWh
IEX	2750-3999	954-1581	4000-5002	2300-2999	572-748
PXIL	2500-3250	250-480	3000-4000	2500-3000	250-392

Table 2 [2]

Hours	UN_MCP Rs/MWh	UN_MCV MWh	UN_Business Rs.	C_MCV MWh	C_Business_NR Rs.	C_Business_ER Rs.	Unclear Volume MWh	Loss of Money Rs.
06:00 -07:00	2750	1460	4015921	614	2456325	1534398	846	2327323
07:00 -08:00	3000	1407	4222876	669	3344651	2002805	739	2216755
08:00 -09:00	3251	1409	4579133	575	2874511	1718795	834	2711201
09:00 -10:00	3699	1386	5126597	573	2864540	1715458	813	3008486
10:00 -11:00	3500	1386	4850650	573	2864540	1714090	813	2846550
11:00 -12:00	3999	1411	5643132	700	3499854	2098128	711	2845341
12:00 -13:00	3251	1467	4769576	701	3504321	2098915	767	2492545
13:00 -14:00	3000	1582	4744453	730	2918131	2182139	852	2555974
14:00 -15:00	3000	1402	4204094	749	2994142	1721550	653	1958811
15:00 -16:00	3000	1252	3754487	699	2794133	2093663	553	1659162
16:00 -17:00	3201	955	3056210	713	2850114	2137108	242	775576
Total			**48967128**	**7292**	**32965264**	**21017049**	**7824**	**25397722**

Table 3 [3]

Hours	UN_MCP ₹/MWh	UN_MCV MWh	UN_Business ₹	C_MCV MWh	C_Business_NR ₹	C_Business_ER ₹	Unclear Volume MWh	Loss of Money ₹
06:00 -07:00	2500	400	1000000	312	936000	780000	88	220000
07:00 -08:00	3000	300	900000	300	-	900000	0	0
08:00 -09:00	3250	350	1137500	291	1164000	873000	59	191750
09:00 -10:00	3250	350	1137500	292	1168000	876000	58	188500
10:00 -11:00	3250	350	1137500	292	1168000	876000	58	188500
11:00 -12:00	3250	350	1137500	350	-	1050000	0	0
12:00 -13:00	3000	400	1200000	391	1564000	1173000	9	27000
13:00 -14:00	3000	480	1440000	392	1176000	1176000	88	264000
14:00 -15:00	3000	480	1440000	393	1179000	1179000	87	261000
15:00 -16:00	3000	380	1140000	293	879000	879000	87	261000
16:00 -17:00	3200	250	800000	250	800000	800000	0	0
Total			12470000		10034000	10562000	534	1601750

UN_ =Unconstrained

C_ = Constrained

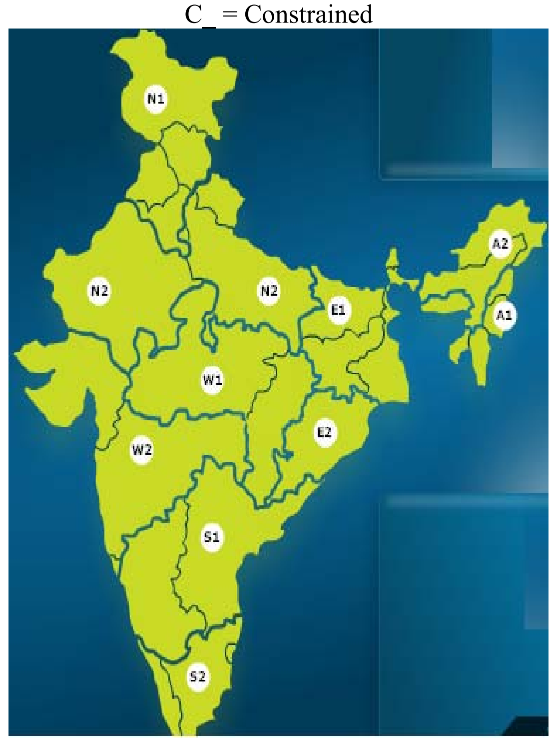

Fig.2

V. Description of the proposed Special Protection Schemes

(i) SPS for 400KV Farakka –Kahalgaon

In Low hydro season, 400 KV Farakka-Kahalgaon D/C gets critically loaded due to high drawal by NR, whenever generation at Farakka is full but low at Kahalgaon STPS. Tripping of one circuit drastically increases the loading on other circuit. Therefore, an SPS is proposed for the same. From the simulation studies it is found that power flow in Farakka-Kahalgaon line has a sensitivity of 45 % with Farakka Generation. The 95 KM line which is of twin moose conductor can be loaded upto 800 MW/Ckt.

The proposed SPS continuously monitors the Farakka-Khalgaon flow, generation of different units at Farakka along with CB status of each of the circuits of 400 KV Farakka-Khalgaon D/C. The SPS remains idle unless and until it receives an actuating signal initiated by tripping of any one circuit between Farakka & Kahalgaon**.**

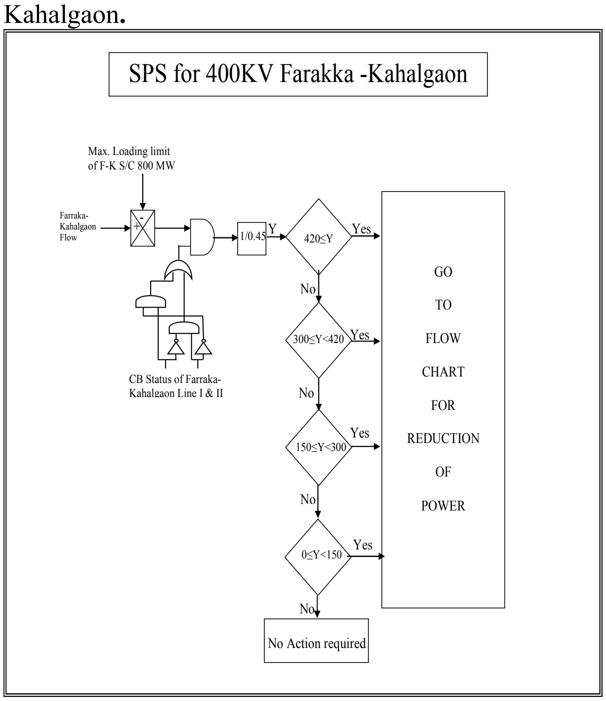

Fig.3

Assuming post-contingency power flow in the healthy circuit to be "**A**" MW, after tripping of other circuit allowable flow to be 800 MW, the circuit is being overloaded by A – 800 = "**B**" MW. Since the Farakka-Kahalgaon line flow has a sensitivity of 45 % with the generation at Farakka, to reduce the line loading by B MW a reduction of **B/0.45** MW generation at Farakka is required. The logic for reducing generation of Farakka (shown in Fig 5) has been designed in such a manner that no unit generation falls below a certain minimum level, which depend on station specific limitations.

Farakka-Kahalgaon flow also depends on whether West Bengal is underdrawing or overdrawing (with respect to schedule). Thus the generation reduction practically achievable at Farraka may not be adequate to provide the desired relief in the line loading and manual control of net interchange of the concerned constituents will have to be resorted to by the respective State Load Despatch Centers.

(ii) SPS for 400KV Farakka -Malda

In low hydro season, 400 KV Farakka-Malda is critically loaded on account of high generation at Farakka, less drawal by West Bengal and high drawal by NR and NER. Tripping of one circuit leads to shifting of almost 90% of the interrupted power to the other circuit resulting in exceeding the emergency loading limit of the latter. Therefore an SPS is proposed for the same. From simulation studies, it is found that power flow in Farakka-Malda line has a sensitivity of 30 % with Farakka Generation. The 40 Km 400 kV twin moose line can be loaded upto 950 MW/Circuit. However the SPS is designed initially to limit the single circuit flow to 850MW. Subsequently, the flow limit would be enhanced in step of 50MW after experience of SPS operation in subsequent events and confidence is gained.

The proposed SPS continuously monitors Farakka-Malda flow, generation of different units at Farakka along with CB status of each of the circuits of 400 KV Farakka-Malda D/C. The SPS remains idle unless until it receives an actuating signal cause by tripping of any one circuit between Farakka & Malda.

Assuming post-contingency power flow in the healthy circuit of Farakka-Malda is "**A**" MW, allowable flow in each circuit is 850 MW, the healthy circuit is being overloaded by A – 850 = "**B**" MW. Since the Farakka-Malda line has a sensitivity of 30 % with the generation of Farakka, to reduce the line loading by B MW a rapid reduction of **B/0.30** MW in generation at Farakka is required. The logic for reducing generation of Farakka (shown in Fig 5) has been designed in such a manner that no unit generation falls below a certain minimum level, which depends on the station specific limitations.

Farakka-Malda flow also depends on whether West Bengal is underdrawing or overdrawing with respect to its schedule. Thus the generation reduction practically achievable at Farraka may not be adequate to provide the desired relief in the line loading and manual control of net interchange of the concerned constituents shall have to be resorted to by the respective State Load Despatch Centers.

(iii) SPS for 400KV Binaguri –Purnea

In high hydro season due to pooling of the full generation from Tala, Teesta and surplus in NER at Binaguri substation, all the four 400 KV circuits

between Purnea and Binaguri remain heavily loaded continuously and tripping of one circuit may cause the emergency loading limit of any of the remaining circuits to be exceeded . The situation is likely to be further aggravated after commissioning of Palatana (760 MW) and Bongaigaon (750 MW) generating stations in NER. Therefore, to take care of such situation, an SPS is proposed to prevent cascaded outage of all the circuits. The line length of 400 KV Purnea-Binaguri Line I & II(Twin-Moose) is 168 KMs and that of Line III & IV(Quad-Moose) is 160 KMs, So these lines can be loaded upto 750 MW/ckt (Twin moose) & 1200 MW/ckt (Quad Moose) respectively.
The proposed SPS continuously monitors the Purnea - Binaguri flow, generation of different units at Teesta along with CB status of all four 400 KV Purnea-Binaguri lines. The SPS remains idle unless and until it receives an actuating signal caused by tripping of any one circuit between Purnea & Binaguri.

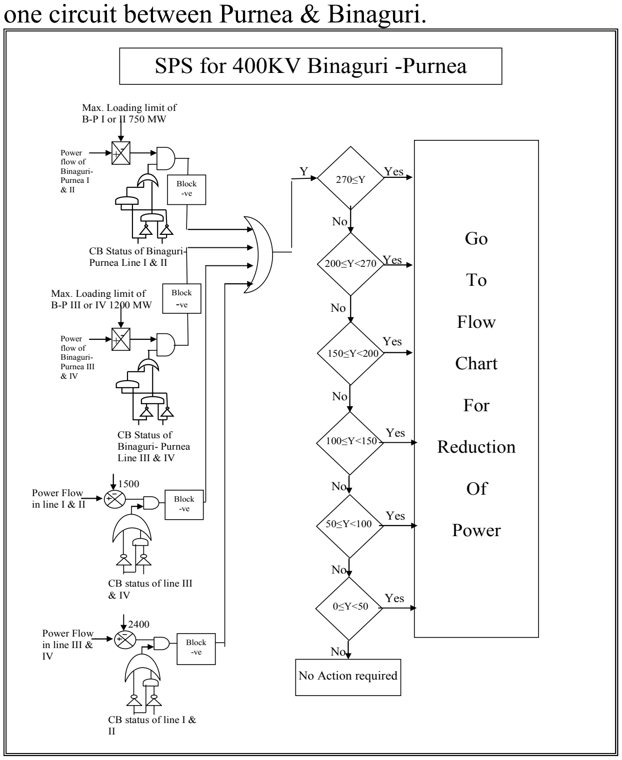

Fig.4

Depending upon which circuit trips, the SPS takes different actions (one set of action for tripping of either circuit I or II and another for tripping either of circuits III & IV).For example if one of the twin moose circuits trips and power flow in the other twin moose circuit becomes "**A**" MW, and sum of power flow in line III & IV becomes "**C**" MW. Under this condition, the healthy twin moose circuit is being over loaded by A-750 = "**B**" MW, while the quad moose circuits are overloaded by C-2400 = "**D**" MW. If both B and D are positive, then it is required to reduce the generation at Teesta by "**B + D**" MW to bring back the flow in all the circuits within allowable limits, since the generation of Teesta directly affects the power flow of Purnea-Binaguri. Otherwise (i.e. if D is negative) B MW reduction in generation will be sufficient.
However, as Purnea – Binaguri flow also depends upon the injection by NER the latter needs to be manually controlled in case desired relief is not forthcoming.

(iv) SPS for 400KV Purnea –Muzaffarpur

In high hydro season due to pooling of more than 2000MW hydro power from NER, Tala & Teesta at Binaguri substation, as well as thermal surplus landing at Purnea through Malda-Purnea line, 400 kV Purnea-Muzaffarpur carries almost 1000MW/circuit continuously and tripping of one circuit may cause emergency loading limit of the other circuit to be exceeded. Therefore an SPS is proposed for the same. The 242 KM 400 kV Purnea-Muzaffarpur D/C line which is having Quad Moose conductor and a series compensation (40 % fixed & 15 % dynamic), can be loaded upto 1500 MW per circuit.
The proposed SPS continuously monitors the Purnea - Muzaffarpur flow, generation of different units at Teesta along with CB status of each of the circuit of 400 KV Purnea-Muzaffarpur D/C. The SPS remains idle unless and until it receives an actuating signal caused by tripping of any one circuit between Purnea & Muzaffarpur.
Assuming the post-contingency power flow in the healthy circuit of Purnea-Muzaffarpur is "**A**" MW, allowable flow 1500 MW, the circuit would be overloaded by A – 1500 = "**B**" MW. Since the line flow has almost 100% sensitivity with Teesta generation, it is required to reduce the generation at Teesta by B MW to bring back the flow in line within allowable limits. However, as Purnea – Muzaffarpur flow also depends on the injection from NER, the same has to be manually controlled in case the desired relief is not forthcoming.

(V) SPS for IPPs

Eastern Region is rich in coal reserves due to which IPPs are coming up in large number. The transmission access plan devised for evacuating power from these IPPs involves construction of pooling stations where the power from several IPPs would be pooled and power transmitted to deficit regions through high capacity 765kV/1200kV corridors. In the deficit region, depooling will take place at several nodes along the backbone network.
Due to delay in application for connectivity and long term / medium term transmission access and signing of agreement by the IPPs, the development of pooling stations is also getting delayed with respect to integrating generating units of these IPPs to the grid. As an interim measure, an IPP is allowed to connect to the ISTS by loop in and loop out of the existing corridors.

Such injection from IPPs is likely to load the existing network closer to allowable limits and require Special Protection Schemes to control the line loadings under credible transmission contingencies. Since manual actions are invariably delayed and may be inadequate, automation through SPS has been proposed by ERLDC for all the upcoming IPPs with temporary connectivity till they are connected to their designated pooling stations as per the planned transmission system. ERLDC has already prepared two schemes: one for Sterlite Energy Ltd., and the other for Maithon Power Ltd. / Mejia 'B' power station. Mejia 'B' (2X500MW) has been connected by loop-in-loop-out of one circuit of 400KV Jamshedpur-Maithon D/C and MPL (2X525) is initially getting connected to Maithon substation of POWERGRID. The injection from these power stations is likely to cause high loading of 400kV Maithon-Kahalgaon D/C line (575MW/ckt) and also critical loading on Kahalgaon-Biharshariff Q/C and Kahalgaon-Patna D/C lines. SPS has been designed for these power stations to run back generation in the event of tripping of any one of Maithon- Kahalgaon D/C.

Generic Flow Chart for Reduction of Power

The following flow chart illustrates the philosophy of attempting a reduction of '**Y**' MW generation in a plant having '**n**' identical units. The logic takes care that generation of no unit is reduced below a certain level '**M**' MW on consideration of technical constraints. It is presumed that the SPS signal for ramping down of generation would be given to the load limiters of various units for faster reduction of generation within few minutes.

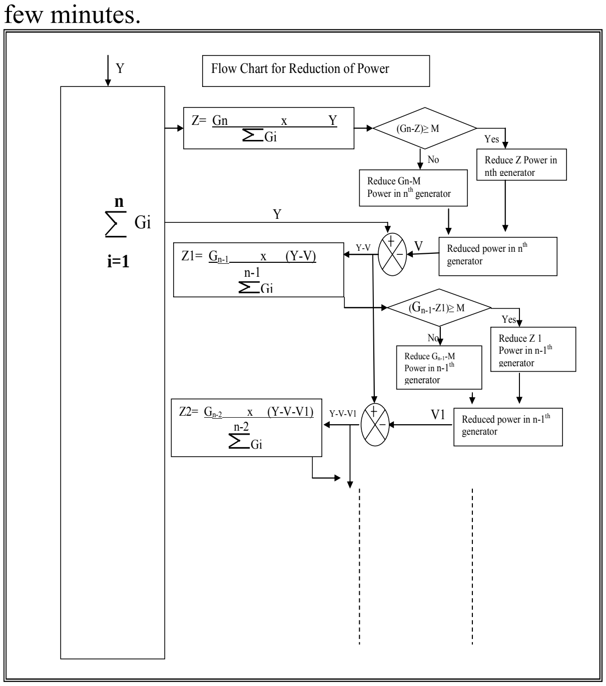

Fig.5

VI. Conclusion

A number of SPSs have been proposed in this paper, all of which aim at maximizing utilization of the transmission system, without compromising on security. By allowing transmission lines to be loaded upto their practical loading limits, market operation can be facilitated to the fullest extent, and backing down of cheap generation can be avoided. The estimated backing down due to winter flow gate constraint would alone be of the order of 600MU in three months of every year. The loss of opportunity cost to ER would be order of ₹300 Cr. The loss of revenue for even eight hours could fund all the proposed SPS. The SPS schemes proposed are to be kept operational till the system strengthening schemes planned are commissioned and the desired level of system adequacy is achived.

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