Corrective Measures for the Effective Load Management and Control Under Disturbance at Bhusawal Thermal Power Station: Case Study

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Abstract A modern power grid needs to become smarter in order to provide an affordable, reliable, and sustainable supply of electricity. The objective of this work is to investigate the discrepancies in power flow control under the abnormal circumstances and to maintain grid stability. This paper reports investigation into the factors that influence the dynamic behavior of the power control from Bhusawal Thermal Power Station (BTPS), India. The problems of existing power system are discussed by considering the case studies of BTPS substation and very efficient solutions are proposed to resolves these hurdles. Load flow studies are carried out for different cases, considering realistic load condition before and after disturbances. Simulation is performed in MATLAB environment and recorded parameters are compared with simulation results.

Introduction

An electrical power grid is a critical infrastructure, whose reliable, robust, and efficient operation greatly affects national economics, politics, and people's everyday life. Power grid crises, which have frequently taken place at world, alert the importance of power grid crises management. With the development of interconnection of big power grid, a small-disturbance stability of a power system should not be ignored. Grid applications access distributed, and often shared resources. One consequence of this resource sharing is that measured application performance can vary widely and in unexpected ways. To respond to changing execution conditions, applications and grid systems must be nimble and adaptive.

The analytical basis for an application of slow coherency theory to the design of an islanding scheme discussed in the literature [1], employed as an important part of a corrective control strategy to deal with large disturbances. Investigations about pre-planned switching events and fault events explained in the article [2], lead to islanding of a distribution subsystem and formation of a micro grid. The studies show that an appropriate control strategy for the power electronically interfaced distributed generation (DG) unit can ensure stability of the micro grid and maintain voltage quality at designated buses, even during islanding transients. A three-phase four-wire grid-interfacing power quality compensator for micro grid applications is presented in the article [3]. The compensator is proposed for

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J. Inst. Eng. India Ser. B (April–June 2014) 95(2):163–173

use with each individual DG system in the micro grid and consists of two four-phase-leg inverters (a shunt and a series), optimally controlled to achieve an enhancement of both the quality of power within the micro grid and the quality of currents flowing between the micro grid and the utility system.

A grid interfacing power quality compensator for three-phase three-wire micro grid applications with consideration of both the power quality of the micro grid and the quality of currents flowing between the micro grid and utility system is explained by the authors [4]. The case examined in [5] is a power park of several inverter based DG in relatively close proximity. In small grids with high proportion of nonlinear and unbalanced loads, it is also important to actively control the waveform quality in terms of harmonics, transient disturbances, and balance. A flexible active power control based on a fast current controller and a reconfigurable reference current selector is proposed in the literature [6], whereas, the power flow control problem of a grid connected inverter in DG applications is given in the article [7]. A real and reactive power control solution is proposed on the basis of an existing voltage control strategy developed for island operations. A power system frequency control strategy is designed [8], which is mainly used to improve the stability of the islanding power system. The balanceable power before disturbance and the capacity of the removed power can be used to calculate the power deficiency. Then, appropriate load can be shed adaptively. A four-leg shunt multifunctional grid connected power quality compensator is mentioned in the literature [9]. The compensator reference currents are generated using the instantaneous p-q-r theory. A digital controller is used to implement dead-beat current control. The dynamic models in MATLAB Simulink which investigates the behavior of doubly fed induction generator during unbalanced grid voltage condition is explained [10], and provides information about controllers in separated positive and negative sequence.

Large signal transient load model to represent the composite power electronic load at a network bus is explained in the article [11]. Traditional load models do not account for the transient responses of power electronic loads which occur at the onset and clearing of voltage sags. In order to design an efficient communication scheme and examine the efficiency of any networked control architecture in smart grid applications, we need to characterize statistically its information source, namely the power grid itself. Study of both the topological and electrical characteristics of power grid networks based on a number of synthetic and real world power systems are discussed in the literature [12]. A three step control methodology is proposed [13] to manage the cooperation between these technologies like DG, distributed storage, and demand side

load management, focused on domestic energy streams. Here, using good predictions, in advance planning and real time control of domestic appliances, a better matching of demand and supply can be achieved.

A modern power grid needs to become smarter in order to provide an affordable, reliable, and sustainable supply of electricity. A vision for the future of smart transmission grids in which their major features are identified [14] that functionally consists of three interactive, smart components, i.e., smart control centers, smart transmission networks, and smart substations. Vision of next generation monitoring, analysis, and control functions for tomorrow's smart power system control centers is discussed by some authors [15]. The present control center technology and the vision of the next generation monitoring, analysis, and control functions are also presented. The implementation of highly realistic real time, massive, online, multi time frame simulations is proposed [16] as a means for building a common vision of smart grid functions among politicians, regulators, managers, operators, engineers, and technicians. An expert operator decision model is described with a view to helping system developers build operator centered and friendly smart grid control systems.

A dc coupled wind/hydrogen/super capacitor hybrid power system is studied in the paper [17]. The purpose of the control system is to coordinate these different sources, particularly their power exchange, in order to make controllable the generated power. An intelligent load shedding algorithm for intentional islanding and an algorithm of synchronization for grid reconnection are explained [18]. A control strategy which utilizes an internal oscillator to maintain the island frequency and a feedback control system to regulate the island voltage for the autonomous (islanded) operation of a four wire, electronically coupled DG unit which can feed a highly unbalanced load is described by the authors [19]. This control strategy provides a set of balanced three phase voltages for the load, despite the load imbalance and parameters uncertainties. To strengthen the small disturbance research can effectively prevent the occurrence of the power grid crises.

This article considered the realistic problem of grid crisis in respect of 132 kV Bhusawal Thermal Power Station (BTPS), India, related to deficiency in generation at any time. It is intended that the power demand should fulfill with quality and reliability and the distribution companies started to collect quality and reliability charges from certain bulk consumers. After restructuring of power system, the issue related to supply and demand become more crucial as the existing power industries have still old generating units (GUs) and old transmission lines. It is observed and recorded under many conditions that the old power plants are about 50 years old and need replacement on priority. These old GUs are suffering due to various

problems. The more common problems are old auxiliaries, boiler tube leakages, poor coal quality, etc. These old GUs are therefore become more unreliable and it is definitely not advisable to depend upon their generations. State already facing problem of power deficiency as about 12 hours load shading is to be performed eventually due to power shortage. Also, the performance of old GUs is unreliable and it makes the situation more critical. In the State, the old GUs are working at Bhusawal, Parali, Nasik, Koradi, etc. and their total generating capacity is about 340 MW. It is always found difficult to rely on these GUs as they can be seldom taken out from the system. Like the old GUs of power plant, the power transmission lines are also become old as they are commissioned about forty to fifty years back. The capacity of power transmission is also required to enhance due to increase in power demand. Most of the lines are of 0.2 aluminum conductor steel reinforced (ACSR) panther conductor and they can carry current up to 482 A at 45 °C. However, it is observed in practice that these conductors carrying current more than 500 A. Therefore, it also came into notice that, the old lines having inadequate power transmission capacity deals problems because of broken conductor, snapping of conductor, etc. These old GUs and lines are responsible to restrict reliable power supply to consumers. Thus, the existing power system is striving under the constraints of old GU's and power transmission lines. Bhusawal Thermal Power Station is one of such example of this kind of problems. The limitations of this power plant and transmission related problems are reported in this article. The emphasis of this paper is to analyze the existing problem at BTPS along

with case study and to propose solutions to overcome this problem. For this purpose, load flow analyses have been made in MATLAB Simulink and the simulation results are compared with the actual recorded values.

Existing Load Flow Scenario of BTPS System

The power generation capacity of BTPS is 210 MW × 2 + 62.5 × 1 i.e. 482.5 MW. It is seen from the single line diagram of BTPS switchyard illustrated in Fig. 1 that the 132 kV bus has two sections named as Grid Control Room (GCR) switch yard and Electrical Control Room (ECR) switch yard and these switch yards are connected by bus sectionalizer circuit breaker called as interconnector 1 and 2. The ECR section has one generator of 62.5 MW, 132/33 kV transformers of 2 × 25 MVA, 132/6.6 kV station transformer of 1 × 10 MVA, 132/25 kV Railway Transformer of 20 MVA and 132/11 kV distribution transformer 16 MVA, along with five numbers of 33 kV feeders. There is no grid feeder connected to this section. This section gets connected to grid only through interconnector 1 and 2 circuit breaker. The GCR section consists of 2 × 210 MW generator units, five grid feeders and four radial feeders. Grid feeders were indicated by arrows in both directions; however, radial feeders were indicated by arrows in one direction. These generating sets are about fifty years old and they are suffering due to chronic problems like tube leakages, old inefficient auxiliaries, etc. These days the quality of coal supplied to power station found poor and it hampers the generation. The maintenance of old auxiliaries
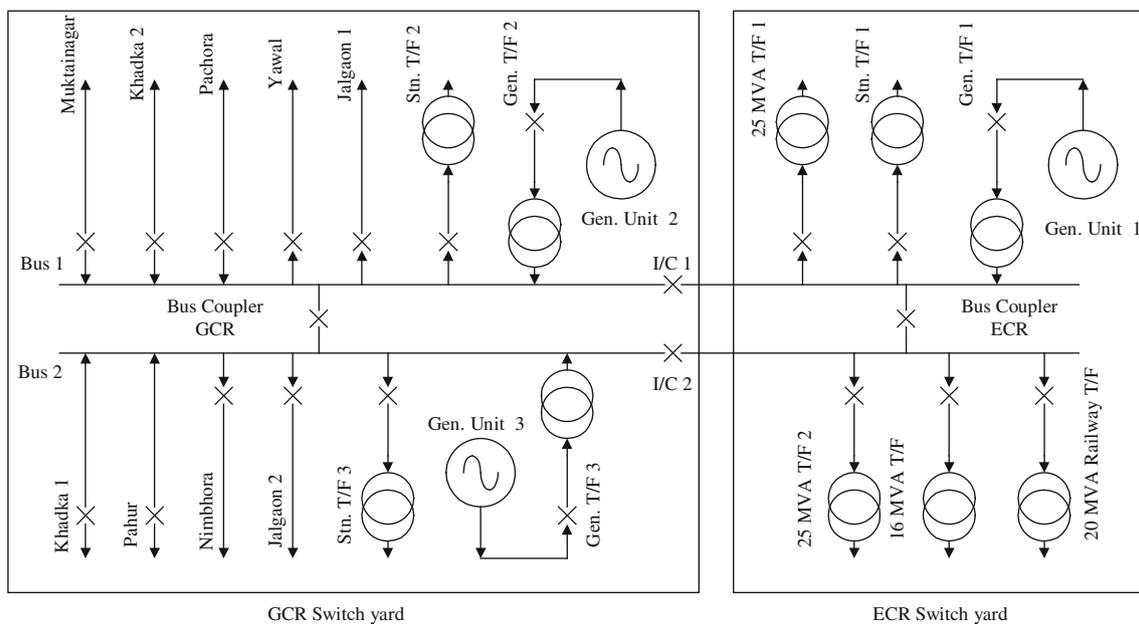

Fig. 1 Single line diagram of BTPS switchyard

and their unscheduled outages also disturb the production of electricity. Another source to this grid connected substation is from 400 kV receiving station, Khadka. In case of complete dark out, the source is always fed from this Khadka receiving station. Two circuits of 132 kV level are connected from Khadka end to BTPS bus and the current carrying capacity of each of the circuit consisting of 0.4 ACSR Deer conductor is 806 A at ambient temperature of 40 °C. The remaining feeders are either grid connected or radial type consist of 0.2 ACSR Panther conductor and have current carrying capacity of 520 A at 40 °C. The load fed from BTPS bus is normally 1,800 A and maximum goes up to 2,000 A as observed from the substation log book. There are four radial feeders emerging from this BTPS bus and fed load about 1,100 A under normal condition, other grid feeders except Khadka receiving station always export power from BTPS bus. The normal and maximum power import and export scenario of all the feeders and GUs is tabulated in Table 1. The capacity of power drawl from 400 kV receiving station, Khadka is restricted to 600 A for each circuit by means of relay settings. The purpose of this Load Trimming Scheme (LTS) provided at is to avoid over loading of ICTs installed at 400 kV receiving station, Khadka and it also limits the excess drawl of power due to conductor constraints. This LTS consist of simple over current relaying circuitry to individual feeder and it provides trip command to all the existing radial feeder simultaneously as each circuit crosses the limit of 600 A fed from Khadka station. Therefore, all the four radial feeders trip at a glance and provide load relief due to operation of LTS and avoid overloading and maintain the power system safely under limit. The (current transformer) CT Ratio of each feeder is 800/1 A and setting of over current relay of this LTS is 75 %, when both the circuits are in service. However, the setting can be enhanced to 100 % when only one circuit is in service. This LTS operated recently four times due to different reasons [20]. All, the four cases are explained in following paragraphs along with load flow study carried out in MATLAB Simulink. To carry the load flow analysis following assumptions have been made [21, 22].

- 132 kV incoming bus bars of BTPS are considered as reference bus.
- Only one transformer is taken into consideration on each ECR side bus which is equivalent to number of transformers on that particular bus.
- Average temperature of transformer is assumed to be 70 °C and frequency to be 50 Hz.
- Load is assumed to be static load and system is in steady state condition.
- Marginal limit for voltage 98–102 % and critical limit for voltage 95–105 %.

Case Studies and Their Load Flow Analysis

Single line diagram of BTPS, as depicted in Fig. 1, has been considered for the load flow analysis. Computer simulation of the substation has been carried out in MATLAB Simulink for steady state, actual load condition data received from BTPS. Load flow analysis has been made with and without disturbance conditions. Simulation results are then compared with the recorded results of BTPS.

Case 1

LTS operated at BTPS on February 16, 2011 at 1349 hours, the power flow import and export scenario is as illustrated in Fig. 2a. The GU 2 was in service and unit 1 and 3 were under outage conditions. Unit 2 was importing 700 A and both the feeders from 400 kV RS Khadka were supplying 500 A each to BTPS bus. The export power was 150 A to ECR switch yard including power requirement of station transformer 1, 80 A to station transformer 2 and 3 both,

Table 1 Normal and maximum power import/export at BTPS

| Sl. No.	Name of feeder	Normal load in A	Max. load in A	Normally import or export	Sl. No.	Name of feeder	Normal load in A	Max. load in A	Normally import or export
1	GU 1	125	250	Import	9	M'Nagar	150	250	Export
2	GU 2	700	700	Import	10	Pahur	150	250	Export
3	GU 3	700	700	Import	11	Pachora	150	250	Export
4	Station T/F 1	30	30	Export	12	Jalgaon 1	300	300	Export
5	Station T/F 2	40	40	Export	13	Jalgaon 2	300	300	Export
6	Station T/F 3	40	40	Export	14	Nimbhora	200	300	Export
7	Khadka 1	300	800	Import	15	Yawal	500	525	Export
8	Khadka 2	300	800	Import	16	ECR	150	250	Export
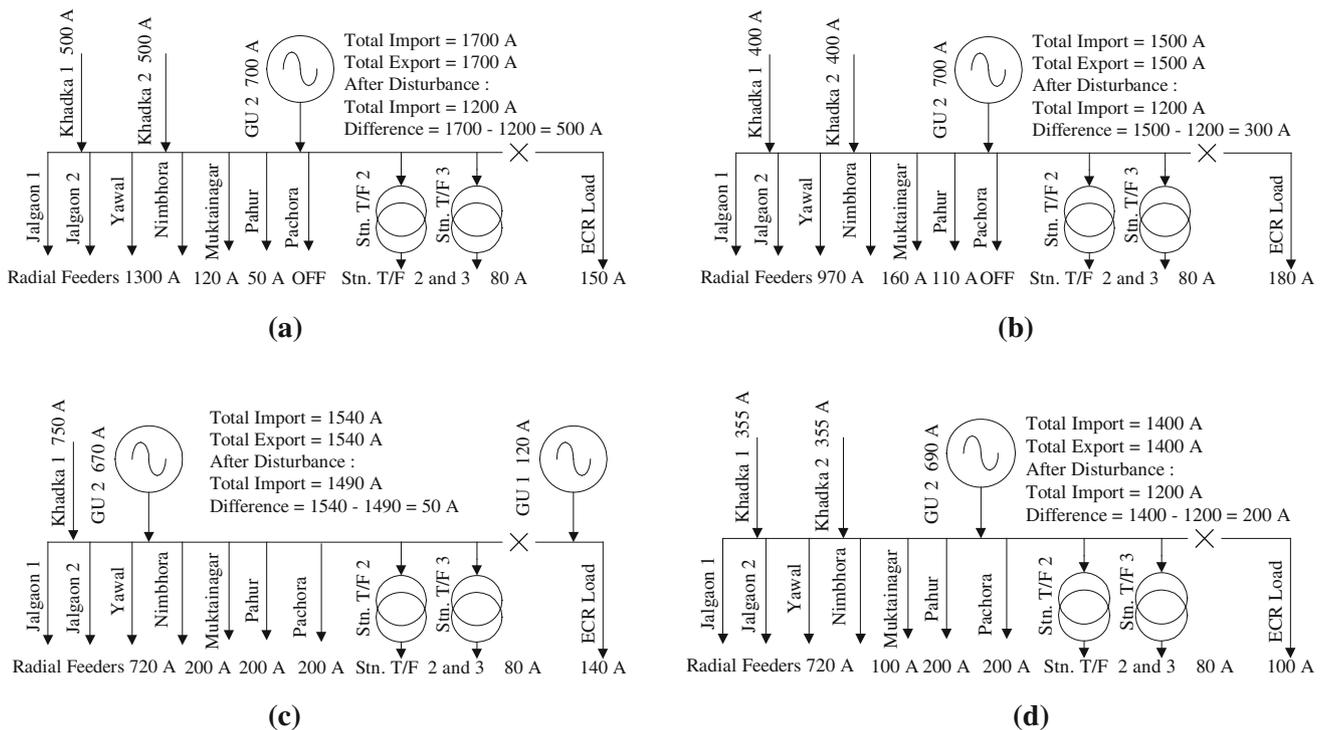
Fig. 2 Power flow scenario under LTS operation for **a** case 1, **b** case 2, **c** case 3 and **d** case 4

120 A to Muktai Nagar circuit, 50 A to Pahur and Pachora circuit was kept off by the instruction from Load Despatcher, Ambazari. At this instant, the total load of all the four radial feeder was about 1,300 A. Generating unit 2 was taken out immediately from the system due to tube leakage problem and hence there was a short fall of 700 A. The setting of LTS over current relay was 75 % as both the lines were in service. As soon as this short fall took place, the import from Khadka RS enhanced to 600 A for each circuit. But, still there was a short fall of 500 A and therefore the LTS initiated trip command to the circuit breakers of all the radial feeders. Therefore, for a short fall of 500 A, load curtailed was of 1,300 A. If the settings are kept at 100 %, under that condition each circuit could draw 800 A, even after that there will be a short fall of 100 A, and for this small short fall LTS definitely curtail the load of 1,300 A.

Case 2

LTS operated at BTPS on February 11, 2011 at 1824 hours, the power flow import and export scenario is as illustrated in Fig. 2b. The GU 2 was in service and unit 1 and 3 were under outage conditions. Unit 2 was importing 700 A and both the feeders from 400 kV RS Khadka were supplying 400 A each to BTPS bus. The export power was 180 A to ECR switch yard including power requirement of station transformer 1, 80 A to station transformer 2 and 3 both,

160 A to Muktai Nagar circuit, 110 A to Pahur and Pachora circuit was kept off by the instruction from Load Despatcher, Ambazari. At this instant, the total load of all the four radial feeder was about 970 A. Generating unit 2 was taken out immediately from the system due to tube leakage problem and hence there was a short fall of 700 A. The setting of LTS over current relay was 75 % as both the lines were in service. As soon as this short fall took place, the import from Khadka RS enhanced to 600 A for each circuit. But, still there was a short fall of 500 A and therefore the LTS initiated trip command to the circuit breakers of all the radial feeders. Thus, the deficiency of 300 A, load curtailed was of 970 A. If the settings are kept at 100 %, under that condition each circuit could draw 800 A, after that there will not be any short fall and thereby there will be no load curtailment.

Case 3

LTS operated at BTPS on December 10, 2010 at 1800 hours, the power flow import and export scenario is as illustrated in Fig. 2c. The unit 1 and unit 3 were in service and unit 2 was under outage conditions. Unit 1 and unit 3 were importing 120 and 670 A respectively. The setting of LTS was raised to 100 % as one the feeder from 400 kV RS Khadka (Khadka 1) was supplying 750 A and another circuit (Khadka 2) was under outage condition. The export power was 140 A to ECR switch yard including power

requirement of station transformer 1, 80 A to station transformer 2 and 3 both. The grid feeders Muktai Nagar, Pahur and Pachora circuit each were drawing 200 A from BTPS bus. At this instant, the total load of all the four radial feeder was about 720 A. Generation of Unit 3 was immediately droop down to 570 A and hence there was a short fall of 50 A only. Hence, LTS initiated trip command to the circuit breakers of all the radial feeders and load curtailed was of 720 A.

Case 4

LTS operated at BTPS on dated November 12, 2010 at 1600 hours, the power flow import and export scenario is as illustrated in Fig. 2d. The unit 2 was only in service and unit 1 and 3 were under outage conditions. Unit 2 was importing 690 A and both the feeders from 400 kV RS Khadka were supplying 710 A totally to BTPS bus. The export power was 100 A to ECR switch yard including power requirement of station transformer 1, 80 A to station transformer 2 and 3 both, 100 A to Muktai Nagar circuit, and 200 A to Pahur and Pachora circuit each. At this instant, the total load of all the four radial feeder was about 720 A. Generating unit 2 was taken out immediately from the system due to tube leakage problem and hence there was a short fall of 690 A. The setting of LTS over current relay was 75 % as both the lines were in service. As soon as this short fall took place, the import from Khadka RS enhanced to 600 A for each circuit. But, still there was a short fall of 200 A and therefore the LTS initiated trip command to the circuit breakers of all the radial feeders. Thus, the deficiency of 200 A, load curtailed was of 720 A. If the settings are kept at 100 %, under that condition each circuit could draw 700 A, after that there will not be any short fall and thereby there will be no load curtailment.

The simulation is carried out for all these four cases and their results are compared with the actual recorded data obtained by BTPS meters. The MICON make meter is used for the purpose of monitoring and recording the data. These results are depicted in Table 2. From the above four different cases and their load flow simulation studies, we could reach to opt following remarks.

1. From case 1 and 3, it came to know that for the deficiency of 100 and 50 A respectively load of the all the radial was curtailed.
2. From case 2 and 4, it is very well clear that the undesired tripping of LTS protection could be avoid if it's over current the relay was set for 100 %.
3. The condition becomes more critical when either one GU or single transmission line is in service.
4. Whenever, there is a generation dip, even though the LTS curtail the load of all four prime radial feeders.

The unreliable generation is the main cause for the operation of LTS and therefore, all the prime important feeders' trip and this badly affect the important bulk consumers and other consumers depends on this feeder connected substations. The problem is in this way formulated and the solution for the effective operation of LTS is considered for the purpose of study in this article. The objective of this paper is to describe the fruitful solution for this problem.

Comprehensive Solution for the Effective Load Flow Control at BTPS

The prime important substations like 132 kV Jalgaon 1 and Jalgaon 2 are the urban and industrial substations respectively. The power supply to entire Jalgaon urban as well as rural area is from these two substations. These are radial substations and reliable only on BTPS bus supply. Another two substations are 132 kV Yawal and 132 kV Nimbhora. These are rural area substations and entire agriculture load is fed from these two substations. In case of Jalgaon 1 feeder trip from BTPS end, Jalgaon 2 also trip on over current protection and vice versa as these two feeders are parallel and terminate at Jalgaon 1 substation bus. From Jalgaon 1 substation bus another feeder emanates for Jalgaon 2 substation. The Jalgaon 1 and 2 feeders carry load up to 600 A

Table 2 Simulation and recorded results

| Case No. | Before disturbance | | | | | | After disturbance | | | | | |
| | Simulation results | | | BTPS meter record | | | Simulation results | | | BTPS meter record | | |
	Bus voltage (kV)	P (MW)	Q (MVAR)	Bus voltage (kV)	P (MW)	Q (MVAR)	Bus voltage (kV)	P (MW)	Q (MVAR)	Bus voltage (kV)	P (MW)	Q (MVAR)
1	$132\llcorner 0°$	384	62	132.4	380.7	65.1	$132\llcorner 0°$	96	15	133.7	95.71	13.67
2	$132\llcorner 0°$	341	40	131.9	344.6	39.8	$132\llcorner 0°$	126	13	132.9	128.9	15.4
3	$132\llcorner 0°$	348	52	131.4	349.2	48.91	$132\llcorner 0°$	195	27	132.4	192.5	29.8
4	$132\llcorner 0°$	317	43	132.1	319.9	43.65	$132\llcorner 0°$	160	19	133.1	163.6	20.1

consulates, the Yawal feeder carry load up to 500 A and Nimbora feeder carry load up to 200 A. Therefore, in case LTS relaying protection operates, all the four radial feeders curtailed load of about 1,300 A. The major cause of undesirable operation of LTS protection is either due to unreliable generation of BTPS power plant and inadequate power transmission capacity from nearby substations because of old and 0.2 ACSR conductor. To avoid the undesired blackouts in this specified regional area, it is mandatory to make the generation stable or the short fall of power under such circumstances should be supplied to BTPS bus by any means. The bottleneck between the supply and demand under the circumstance of LTS operation has to be compensated on priority. There are various constraints observed and studied while putting the solution of this problem. Efforts are made in this article to provide comprehensive solution for the effective operation of LTS under the defined constraints. The model for effective LTS relaying scheme is also developed and its simulation results are presented shows the potential of the approach.

Solution 1: Tying of Radial Substations and Load Diversion

It is come to know from the above discussion that the four important substations are feeding power from only BTPS bus only. Whenever, there is a problem to BTPS bus either due to LTS tripping or due to LBB operation or due to Bus bar protection operated, it will definitely hamper the power import to the bus of these four radial substations. This severely affects all important consumers connected to these substations. If all these four substations tied up with the nearby substations, the entire black out condition due to problem from BTPS side can be avoid to certain extent. These substations should be link for e.g. Jalgaon 1 and 2 can be connected to 132 kV bus of 400 kV RS, Khadka. For this new transmissions line have to be erected. But this task is not found as simple as the State Transmission Company came across the problem of (Right of Way) RoW. To erect new transmission network, land acquisition is the major hurdle as people are unwilling to lend their land for this purpose. This problem shall be resolve by making proper communication, coordination and understanding with the people. In certain cases the possibility of laying 132 kV cable is require to be identify. As soon as all these four substations are connected with nearby other substations, the problem of entire darkening shall be overcome. The tying of substations is illustrated in Fig. 3a.

Solution 2: Strengthen the Parallel Link

The parallel link is connected to the 132 kV bus of BTPS–Muktai Nagar–Bodwad–Malkapur–Khadka and back to BTPS substations as shown in Fig. 3b. This link is unable to supply load demand more than 520 A at 40 °C due to constraints of conductor size i.e. 0.2 ACSR panther conductor. This is an existing corridor and it normally draw 300 A from BTPS bus at power factor about 0.98. Possibility for the application of FACT device is also determined. But due to thermal constraints of the line conductor, this possibility gets vanish. The capacity of this parallel link can be enhanced by replacing the existing conductor by 0.4 ACSR Deer conductor. But this rise the capacity just by 300 A and pushing 300 A from 400 kV RS, Khadka to BTPS bus by this parallel link might be difficult as load on another substations in this ring can hamper this power flow. Therefore, this solution is not recommended.

Solution 3: Additional Link from 400 kV RS Khadka and/or Increase in LTS Relay Settings

It is observed from the above case studies that, in case of strong generation dip or loss of generation, the source available is from 400 kV RS, Khadka. There are two circuits emanating from 132 kV Khadka bus for BTPS bus. Each circuit has CT ratio of 800/1 A and current carrying capacity up to 806 A at ambient temperature of 40 °C. LTS relay is set for 75 % and thus the power flow of each circuit is restricted to 600 A for each circuit. It is strongly recommended that under the existing position, the LTS relay settings must be enhanced to 100 % from 75 %, so that additional 400 A can be available in case of generation dip up to this extent. An additional circuit from 400 kV RS, Khadka to BTPS of 0.4 ACSR deer conductor can eliminate this problem as additional 800 A flow can be available at a glance after the generation or line loss. It is observed that 132 kV additional bay is available at BTPS but at Khadka station no space is available for the erection of new bay and RoW will also be another problem for line erection.

This problem can be resolve if the 132 kV Malkapur feeder emanate from BTPS in spite of Khadka end. The existing Malkapur feeder should terminate at BTPS and new feeder for Malkapur shall emanate from BTPS. This is definitely a concrete solution and one spare bay is available at BTPS. It is observed that there is a problem of diversion of transmission line, this problem can be overcome by making provision of 132 kV power cable. In our opinion this is more suitable and inexpensive solution. This solution is illustrated in Fig. 3c. The dash lines illustrate the proposed modifications. Applications of FACT devices are also studied. The thermal rating of existing 0.4 ACSR Deer conductor is the major constraint and hence it is not recommended to provide FACT device to this short transmission line.

Fig. 3 Comprehensive solution
for the effective operation of
LTS of BTPS. **a** Tying of radial
substations and load diversion,
b strengthen the parallel link
and **c** additional link from
400 kV RS Khadka

(a)

(b)

(c)
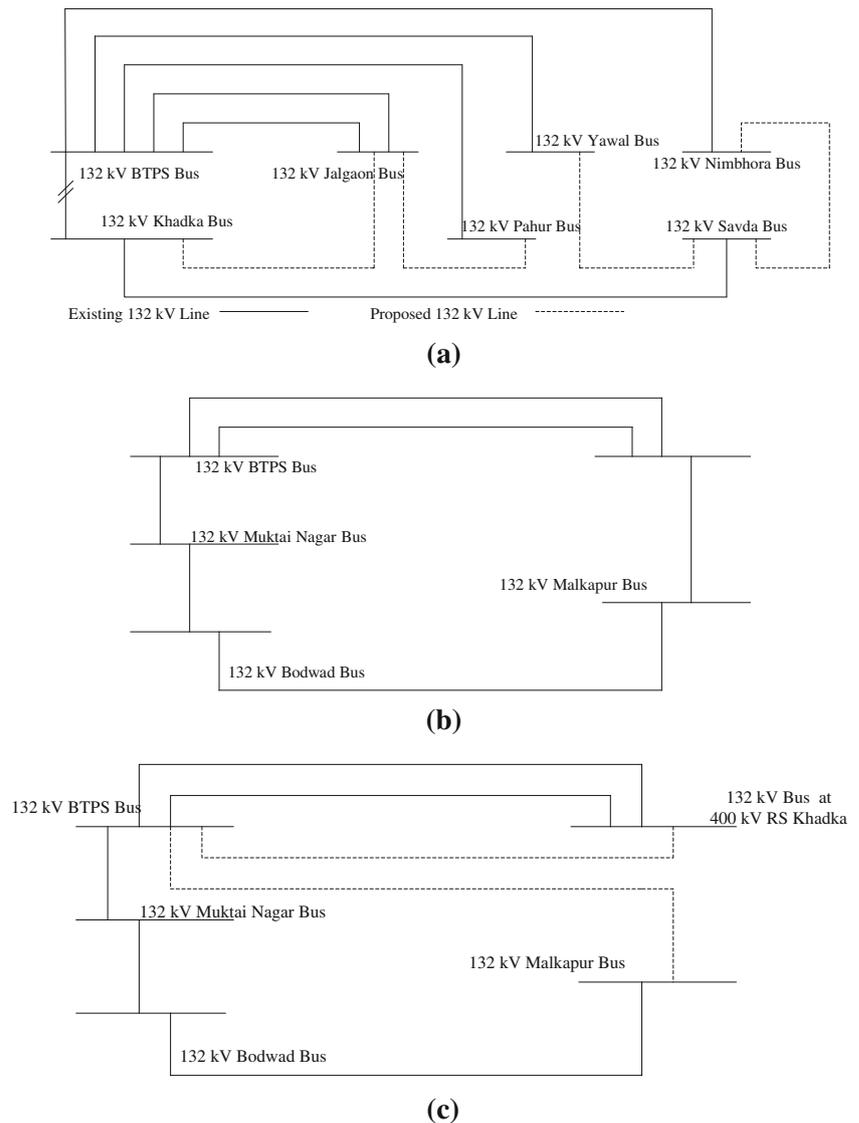
**Solution 4: Development and Testing of Multi Stage
Over Current Relaying Scheme**

It is observed from the above discussed case studies that,
for the deficiency of 50 A, the LTS was operated. If
instead of providing tripping commands to all the four
radial feeders, it might be possible that any one or two
feeders could be tripped. The maximum load of Jalgaon 1
and 2 is always 300 A each and these are twin feeders. If
anyone feeder trip, another feeder always trips due over
load. The maximum load of Yawal and Nimbhora feeders
recorded was 400 and 200 A respectively. Jalgaon 1 and 2
are urban and industrial feeders, however, Yawal and
Nibhora are rural and agricultural feeders, therefore it is
recommended that the Jalgaon 1 and 2 should be given
priority so that their tripping shall be avoided for the
considerable short fall. Making study of all the above

cases, it is strongly recommended to procure multi stage
over current relay for the effective operation of LTS. The
existing simple over current relay shall be replaced by this
relay. The circuit connection diagram for this proposed
multi stage over current relay is depicted in Fig. 4a. The
GUs are also considered in addition to feeders from
400 kV, RS, Khadka. Depending upon the availability of
power at BTPS bus, the multistage relay should take
decision about tripping of relevant feeders. The CT ratios
and ratios of interposing CTs are not mentioned to avoid
complexity of the circuit. The necessary algorithm is
illustrated in Fig. 4b.

The investigation is made for the setting of this proposed
multistage over current relay by considering certain pos-
sible cases as tabulated in Table 3. It is observed, in case 1,
both the lines and GUs are in service, if one GUs become
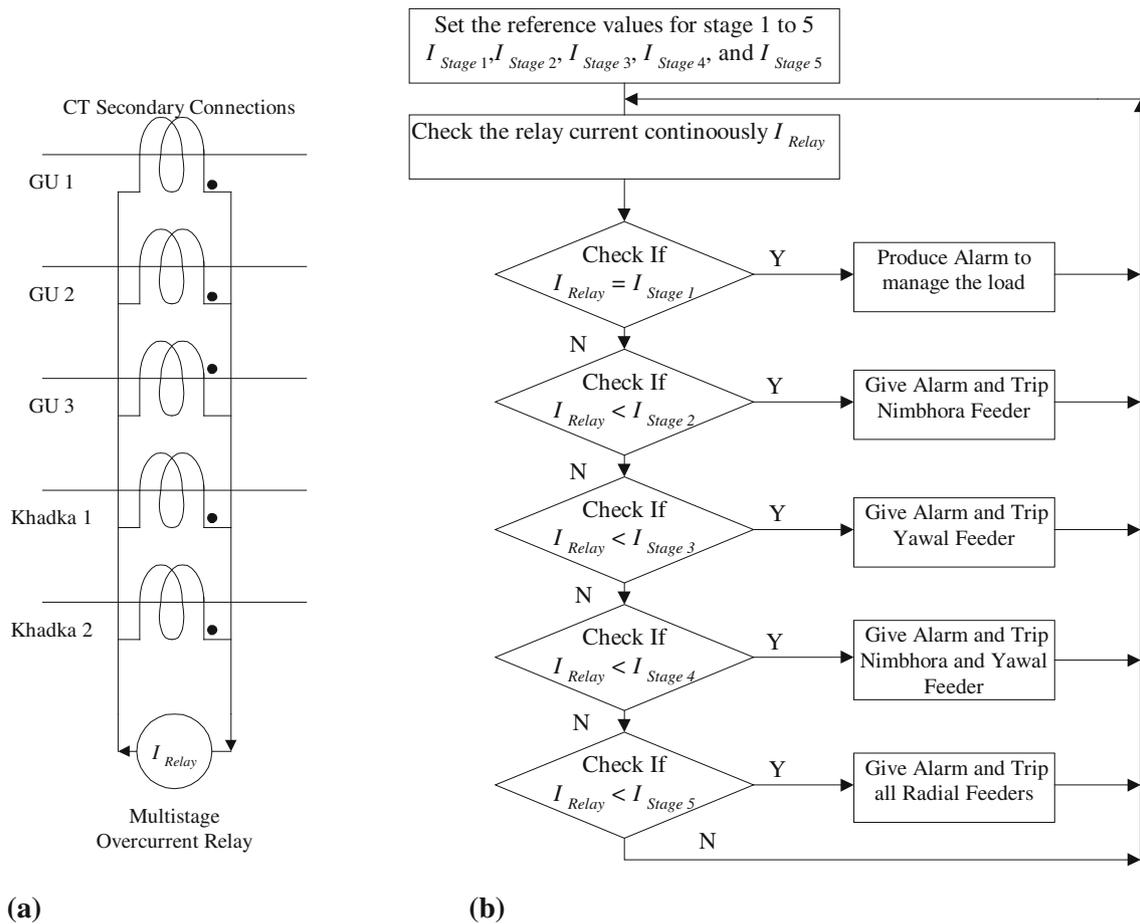off, then the deficiency raised to 700 A. This deficiency

Fig. 4 **a** The circuit connection diagram for this proposed multi stage over current relay and **b** the algorithm for multistage relay

Table 3 Different conditions to analyse the performance of proposed multistage over-current relay

Sl. No.	GU in service	Lines in service	GU become off	Line become off	Deficiency or shortfall	Rise in Current of import feeders		Remarks
						Khadka 1	Khadka 2	
1	2	2	1	0	0	300 + 350	300 + 350	Rise in line load. Alarming condition to monitor the load
2	2	2	0	1	0	300 + 300	–	Rise in line load. Alarming condition to monitor the load
3	2	1	1	0	500	600 + 200	–	Trip Yawal and Nimbhora feeders
4	2	1	0	1	600	–	–	Trip Yawal and Nimbhora feeders
5	1	2	1	0	400	650 + 150	650 + 150	Trip Yawal feeder only
6	1	2	0	1	500	650 + 150	–	Trip Yawal and Nimbhora feeders
7	2	0	1	0	600 + 700	–	–	Manage the load and if GU trip, trip all radial feeders
8	0	2	0	1	400 + 800	800	–	Manage the load and if GU trip, trip all radial feeders
9	2	2	1/2[a]	0	0	300 + 175	300 + 175	Rise in line load. Alarming condition to monitor the load
10	2	2	(½ + ½)[b]	0	0	300 + 350	300 + 350	Rise in line load. Alarming condition to monitor the load

[a] Generation of either GU 1 or 2 drops to 50 %

[b] Generation of both GU 1 and 2 drops to 50 %

Table 4 Plug setting of proposed multistage over-current relay

Sl. No.	BTPS bus import current (A)	Stages of LTS over current relay	Setting of relay (%)	Remark
1	1,950	S_1	65	Provide alarm to manage load
2	1,800	S_2	60	Trip Nimbhora feeder only
3	1,620	S_3	54	Trip Yawal feeder only
4	1,410	S_4	47	Trip Yawal and Nimbhora feeders both
5	Below 1,410	S_5	>47	Trip all radial feeders

shall be fulfilled by the feeders emanating from 400 kV, RS, Khadka by sharing 350 A in each circuit. In case 3, two GU s and one line is in service and the GU sharing 700 A, suddenly taken out from system, thus the load sharing from Khadka 1 raise by 200 A and shortfall of 500 A still exist. Under this circumstance, both Yawal and Nimbhora feeders shall be tripped.

In case 5, it is observed that, one GU and two lines are in service and suddenly the GU is withdrawal from the system, the load on each import circuit raised by 150 A but for the shortfall of 400 A, it is essential to trip only Yawal feeder. The dropdown in generation of GUs is also considered in case 9 and 10. In case 9, generation of either of

GU 1 or 2 falls down by 50 % and it imports 350 A inspite of 700 A. Whereas, in case 10, generation of both the GU s falls to 50 % and each GU import 350 A inspite of 700 A. In both the cases, there will be a significant rise in import from 400 kV, RS, Khadka but LTS will not be operated. Numbers of such combinations related to availability of GUs, lines and drop generation of individual GU s are studied in this article.

Based upon the above proposed connection diagram and these eight cases, it is recommended to provide settings for this multistage relay as mentioned in Table 4. The software program is developed in MATLAB for this effective LTS and its results for the above all condition are presented in Fig. 5a. From the simulation results, it came to know that the over current relaying system functions effectively in these five stages. The performance is tested with the simulated and actual data and it results are depicted in Fig. 5b. This system provides optimized results under the existing constraints by avoiding undesired tripping and useful to maintain the healthy supply.

The above realistic and simulated load flow case studies along with the solutions, emphasis the authors to enlist the following outcome of this article.

1. The existing setting of two lines from 400 kV RS; Khadka should be raised to 100 % from existing 75 % and efforts should be made to tie up the radial substations with nearby sub stations.

2. Additional circuit from 400 kV RS; Khadka should be developed either by transmission line or 132 kV power cable. The existing Malkapur feeder should terminate
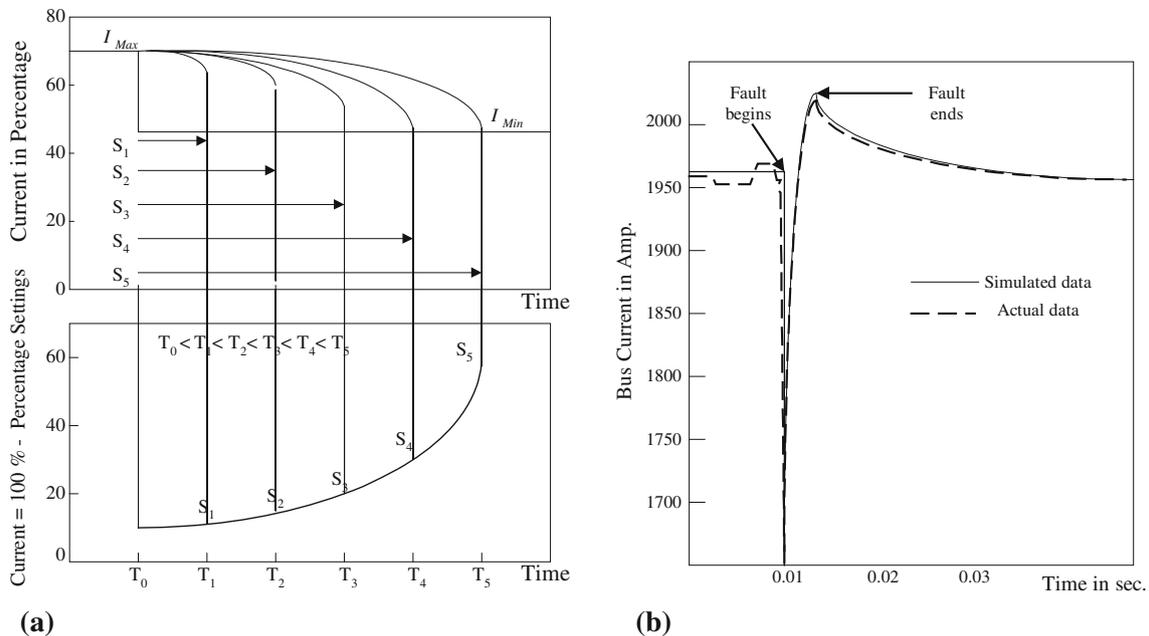

Fig. 5 a Design output of multistage relay for effective operation of LTS and **b** performance test results of simulated data and actual data when GU 1 suddenly taken out from system

at BTPS and new feeder for Malkapur shall emanate from BTPS.

3. Application of FACT devices for strengthening existing parallel link or feeders from 400 kV RS; Khadka did not provide concrete solution to avoid undesirable tripping due to LTS operation.

4. Application of multi stage over current relay with its connection diagram is able to provide the effective solution to optimum level.

Conclusions

This paper investigates existing load flow scenarios of a BTPS bus under various disturbance conditions and performance is evaluated by examine the load flow studies in MATLAB Simulink. The undesired tripping and thereby curtailments of important load is also described due to old GUs in power plants and inadequate capacity of transmission lines. Case studies are discussed to elaborate the critical situation of this substation under shortfall of power supply. In comparison of recorded meter data from BTPS and simulation results with and without disturbance, the deviations in the parameters are found to be acceptable. Efforts are made to strengthen the power system by proposing solutions and development of control system structure in the form of software for multistage relay. The results in respect of multistage over current relaying scheme are depicted with simulated and actual data and it validates the performance under occurrence condition in a satisfactory manner.

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