Final Report

on

Partial Grid Disturbance in Mumbai System

June 2011

Foreword

The aim of this study is to analyze disturbances on 18th and 21st November 2010 in Mumbai system and to find remedies so as not to experience similar situation in future. Hon'able MERC directed IIT Bombay and other power utilities in Mumbai system to form a committee. Based on scrutiny of data received from various utilities, discussions in the group meetings and system studies conducted at IIT Bombay, the committee has finalized the report.

The complexity of protection policies followed by different transmission companies' viz., MSETCL, TPCL, and R-Infra requires more time for standardization. Also, study of islanding and associated load trimming schemes is done. Further, the study on N-1 compliance of upcoming network augmentation schemes in Mumbai system in medium-term is done.

The study results and recommendations of the committee are presented in the succeeding chapters of the report.

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Acknowledgement

We are grateful to all group members from MERC, WRLDC, MSLDC, MSETCL, TPCL, R-Infra and all those people who are directly or indirectly participated in the discussion and helped the committee in bringing valuable finding to the Hon'able Commission. We are also grateful to Mr. S. G. Kelkar, C. E., STU, MSETCL, Mumbai for his continuous support and assistance throughout this assignment.

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Abbreviations and Acronyms

MERC	:	Maharashtra Electricity Regulatory Commission
WRLDC	:	Western Region Load Dispatch Center
WRPC	:	Western Region Power Committee
MSETCL	:	Maharashtra State Electricity Transmission Company Limited
TPCL	:	Tata Power Company Limited
R-Infra	:	Reliance Infrastructure Limited
SLDC	:	State Load Dispatch Center
MSLDC	:	Maharashtra State Load Dispatch Center
STU	:	State Transmission Utility
UFR	:	Under Frequency Relay
OEM	:	Original Equipment Manufacturer
ROW	:	Right of Way
GETCO	:	Gujarat Electricity Transmission Company
VSC	:	Voltage Source Converter
SPS	:	Special Protection System
OLTS	:	Overload Trimming Scheme
PMU	:	Phasor Measurement Unit

Preface

Partial Grid Disturbance in Mumbai system took place on 18th November 2010 at 17:40 hrs and 21st November 2010 at 17:05 hrs. In this matter, The Hon'able Commission issued Notices dated 19th November 2010 and 22nd November 2010 to SLDC, Kalwa, the concerned Licensees and to other Users of intra-State Transmission System regarding suo motu hearing to be held in the matter on 25th November 2010. The Hon'able Commission also issued the order vide Case No. 84 of 2010 dated 1st December 2010.

The Commission directed to review of protection setting at all inter-connection points between two transmission licensees and also between Transmission-Distribution Inter-connection boundary points. The Commission directed that a Committee headed by Professor (Dr.) S. A. Khaparde, IIT Bombay consisting of representatives from SLDC, WRLDC, STU, TPCL, R-Infra and Commission's Officer be constituted for review of existing protection schemes , under frequency relay settings, Islanding scheme, Studies on compliance of (N-1) criteria and investigate the prime reasons for aforesaid two system disturbances. The Chief Engineer (MSLDC), Kalwa was directed to act as Member Secretary to the Committee. The Committee was also directed to suggest remedial measures so that such occurrences can be avoided in future.

On 4th December 2010, the chairman of the committee, Prof. (Dr.) S. A. Khaparde, IIT Bombay sent the Terms of Reference (ToR) to MERC for finalization of working groups. After consultation with Hon'able Member (Technical), MERC, following working groups are formed.

Apex Body:

Sr. No	Name	Designation
1	Dr. S. A. Khaparde	Professor, IIT Bombay
2	Shri S. G. Kelkar	C.E., SLDC, MSLDC, Kalwa
3	Shri S. R. Narasimhan	D.G.M (OS), WRLDC, POSOCO, Mumbai
4	Shri A. H. Kulkarni	Regulatory Expert, MERC

Working Committee Group1: Protection System and Islanding Scheme Review

Sr. No	Name	Designation
1	Shri A. M. Kulkarni	Professor, IIT Bombay
2	Shri S. S. Rajurkar	S.E. (Trans O&M), MSETCL, C.O., Mumbai
3	Shri D. J. Kolhe	DyEE, MSLDC, Kalwa
4	Shri M. V. Kini	DGM, Testing, TPCL
5	Shri R. H. Satpute	Dy.E.E, TCC, MSETCL, Vashi.
6	Shri Avinash Waghambare	AVP, Reliance Infra. Ltd.
7	Shri C. S. Bobade	Chief Manager, WRLDC, POSOCO, Mumbai

Working Committee Group2: System Study Review

Sr. No	Name	Designation
1	Shri Chandresh V Dobariya	IIT Bombay
2	Shri K. D. Daware	DyEE, MSLDC, Kalwa
3	Shri N. R. Sonkavday	S.E. (STU), MSETCL, C.O., Mumbai.
4	Shri V. R. Shrikhande	DGM, LCC, TPCL
5	Shri Vikas Sonar	AVP, Reliance Infra. Ltd.
6	Smt. Pushpa S.	Manager, WRLDC, POSOCO, Mumbai
7	Shri Amit Kulkarni	A.E. (STU), MSETCL, C.O., Mumbai

The working groups had many rounds of discussion among the members as well as with Apex Body. Based on these findings, an interim report was submitted to MERC in January 2011. The committee also made a presentation to the Commission on 28th January 2011. Based on the suggestions received during this meeting, deliberations during the meeting of the committee members, and studies done, this final report is being submitted.

Chapter 1

Introduction

1.1. Background of Grid Disturbance in Mumbai System

Mumbai power system experienced a grid disturbance leading to partial blackout on 18th November 2010 at 17:40 hrs and 21st November 2010 at 17:05 hrs. The coming sections of this chapter present chronological details of both the occurrences.

1.1.1. Partial Grid Disturbance in Mumbai system on 18th November 2010

a) Maharashtra System Conditions
(Prior to Disturbance)

- State Catered Demand : **13007** MW
- State Generation : **9583** MW
- Central Sector (Receipt) : **3424** MW
- System Frequency : **49.76** Hz
- Mumbai System
  - Mumbai Catered Demand : **2599** MW
  - TPC Hydro : **186** MW
  - TPC Thermal : **1257** MW
  - R-Infra Thermal : **498** MW
  - Exchange with MSETCL : **658** MW
- Transmission Equipments Outage :

1) 220 kV Salsette [TPC-T] Bus- Coupler : status OPEN
   Bus-Coupler is normally kept open in order to control loading on 220 KV Kalwa-Salsett D/C

2) 220 kV Borivali [MSETCL]- Borivali [TPC] : status OPEN

   Flow on this line normally remains above 300 MW and during Mumbai peak 380 MW.

   Major source to Borivali is from Kalwa S/s During forced outage of ICT-1 at Kalwa line kept off from 19th Oct.

3) 220 kV Kalwa - Borivali [MSETCL]: status OPEN

   This was planned outage for numerical relay commissioning.

b) The sequence of events of the disturbance on 18th November 2010 is listed in Table 1in chronological order.

Table 1. Sequence of Events of Disturbance in Mumbai Suburban System

Sr. No	Time	Sequence of Events
1	**17:39:17**	At **17:39:17:852 Hrs** 220 kV Trombay-Salsette ckt-1 carrying 170 MW, tripped on phase to phase fault caused due to kite string in span 70-71 at Tagorenagar, Vikroli.
2	**17:44:43**	At **17:44:43:868 Hrs** 220 kV Trombay-Salsette ckt-2 carrying 290 MW, tripped at 220 kV Salsette end. Earlier both the lines where carrying 170 MW each.
3		Prior to tripping, at 220 kV Salsette, Bus coupler was off.
4		R-Infra system remain connected to Borivali (TPCL) and further to Borivali (MSETCL) on 100 kV BO-BO Lines.
5	**17:44:44**	Borivali (TPCL) started drawing from Borivali(MSETCL) on 100 kV Borivali, due to network configuration. 220/100kV, 2X125 MVA ICT's at MSETCL Borivali, which were carrying 180 MW (Pre fault loading) tripped on over load.
6		Due to tripping of Borivali ICT, Borivali(TPCL) load shifted on Reliance network.
7		This has resulted in reversal of power flow from 190 MW, from Borivali(TPCL) to RInfra Aarey to 274 MW export from RInfra Aarey to Borivali(TPCL).
8		Reliance network was carrying about 950 MW with a Dahanu generation of 498 MW. Reliance system remained connected to Boiser(MSETCL) system.

Sr. No	Time	Sequence of Events
9	**17:45:19**	Drawal from Boisar(MSETCL) increased and 220 kV Boisar-Versova carrying 319 MW and 220 kV Boisar-Dahanu carrying 229 MW consequently tripped on over- load.
10	**17:45:19**	Load of 950 MW remained connected to Reliance network having source of 498 MW, which resulted in dipping of frequency at **17:45:19:563Hrs**, Automatic load shedding of 400 MW was initiated at 48.00 Hz.
11	**17:45:20**	Due to further frequency dipping to 47.6 Hz, islanding scheme at Aarey operated resulting in tripping of both TPC lines at Aarey at **17:45:20:252 Hrs** which was feeding to Borivali(TPCL) S/s**.**
12		Due to load throw off on account of loadshedding on U/f and disconnection of TPCL lines at Aarey, frequency shotup to 51.75 Hz of islanded system.
13	**17:45:37**	During these frequency oscillations, the GT-1 at Dahanu TPS tripped on overspeed at **17:45:37 Hrs.**
14	**17:45:39**	Dahanu unit 2 remained in service with the island load of 370 MW. Thereby tripping on under frequency at **17:45:39 Hrs**.
15		Thus Total AC failure in R Infra network was of 770 MW.
16	**17:46:21**	220 kV Bus coupler at 220 kV Salsette was closed at **17:46:21:564 Hrs** and supply to Borivali(TPCL) restored.
17		Total restoration at 19:04 hrs 664MW load was restored in Rel Infra system (400 MW from TPCL and 264 MW from Boisar)
18		Unit-2 synchronized at 2014 hrs and Unit-1 synchronized at 21:18 hrs.

*Time details are taken from SCADA system at SLDC, Kalwa; TPCL, Trombay; and R-Infra, Aarey.

* All the control centers in Mumbai region viz., SLDC, Kalwa; TPCL, Trombay; and R-Infra, Aarey are time synchronized using GPS.

c) System Restoration

1] 220 KV Trombay-Salsette-II taken in service at 17:48 hrs

2] 220 KV Borivali (T)-Aarey (R)-I at 17:55 hrs (Aarey sub-station restored)

3] 220 KV Boisar (MSETCL)- Dahanu(R) at 18:03 hrs (aux supply toDTPS)

4] 220 KV Trombay-Salsette-I at 18:12 hrs

5] 220 KV Boisar (MSETCL)-Versova (R) at 18:15 hrs

6] 220/100 KV Borivali(M) 125 MVA ICT-I at 18:06 hrs

7] 220/100 KV Borivali(M) 125 MVA ICT-II at 18:10 hrs

8] At 19:04 hrs 664 MW load was restored in R-infra system. (400 MW from TPCL and 264 MW from Boiser).

9] DTPS U-2 syn.at 20:14 hrs. & DTPS U-1 syn.at 21:18 hrs.

1.1.2. Partial Grid Disturbance in Mumbai system on 21st November 2010

a) Maharashtra System Conditions

(Prior to Disturbance)

- State Catered Demand : **11706** MW
- State Generation : **9114** MW
- Central Sector (Receipt) : **2592** MW
- System Frequency : **50.14** Hz
- *Mumbai System*

  Mumbai Demand : **1792** MW

  TPC Hydro : **0** MW

  TPC Thermal : **936** MW

  R-Infra Thermal : **496** MW

  Exchange with MSETCL : **360** MW

b) Following lines tripped

- 220 KV Trombay-Dharavi-V & 220 KV Trombay-Salsett-II tripped on fault at 1705 Hrs.

- 220 kV Trombay-Dharavi VI tripped at 1710 Hrs. This has resulted in failure of 220 kV supply to Dharavi and tripping of other 110 kV lines on over load, causing shut down to Dharavi substation.
- Bhira plant was not working due to work in tailrace by irrigation department.
- No source to Dharavi on 220 KV Bhira-Dharavi D/C
- 220 KV Dharavi – Backbay supply failed at Backbay.

c) Area affected

Load at Dharavi	– 299 MW
Load fed from Dharavi at Vikhroli	-- 67 MW
Load fed from Dharavi at Mahalaxmi	-- 30 MW
Load fed from Dharavi at Backbay	-- 29 MW
Total Load affected	-- 425 MW

- Supply affected in full or partial in the part of Marin Drive, Mantralaya, Backbay, Nariman point, Cuff-Parade, Colaba, Lower Parel Mahalaxmi, Chinchpokali, Bombay central Lalbag, Dadar, Mahim, Matunga, Sion, Dharavi, Bandra, Kurla, Ghatkopar, Vikroli, Chunabhatti, Mankhurd, Chembur.

d) System Restoration

- 17:14 Hrs supply extended to Mahalaxmi from 110 KV Parel and about 30-35 MW load restored
- 17:23 110 KV Trombay-Dharavi – II taken in service
- 17:27 220 KV Trombay-Dharavi – VI taken in service
- 17:28 110 KV Dharavi-Vikroli taken in service
- 17:30 Hrs supply extended to Backbay from 220/110 KV Carnac S/s about 35 MW load restored including Mantralaya

- 17:32 Railway feeders at Dharavi & Vikroli charged Central Railway section from Chinchpokali to Mulund and Western Railway section from Dadar to Vileparle affected during 17:10 to 17:32 Hrs for about 22 min.
- 17:52 Hrs 220 KV Trombay-Dharavi – V taken in service
- 18:01 Entire load at Dharavi & Vikhroli restored
- 18:02 220 KV Trombay-Salsette taken in service
- 19:49 110 KV Dharavi – Mahalaxmi taken in service

Chapter 2

Review of Protection System and Islanding Schemes

2.1. Introduction

R-Infra carried out testing of insulation breakdown strength of the kite string at VJTI, Mumbai on 27.5.2009. Test results shows that out of six samples tested, two samples found to have lower insulation breakdown strength. This indicates that the fault on 18th was primarily initiated by the kite string. However, the more concerting part was the consequences of the line tripping leading to cascade tripping of other transmission lines, mainly due to overload.

The existing protection and islanding schemes particularly need to be revisited and improved to avoid similar occurrences in coming time. Further sections in this chapter include suggestions of expert committee on existing protection and islanding schemes.

2.2. Review of Protection System

The committee has come out with following suggestions and recommendations by discussing various aspects of protection scheme.

1. The group discussed the possibility of employing auto-reclosure for 220 kV level. The concerns for employing auto-reclosure at 220 kV level are:
    a. Generator-Turbine shaft stress at the Trombay generators.
    b. If the fault happens to be a permanent one, then stability may be jeopardized due to the additional disturbance.
    c. There are several network branches with combination both overhead lines and cables (hybrid lines). Auto-reclosure for cable faults is not recommended since they are unlikely to be temporary in nature. The current and voltage measurements at the two ends of the combination may not be able to discriminate whether a fault is in the cable segment or in the overhead line section.

d. Some lines pass through slum areas and danger to humans is apprehended.

Investigation of these concerns will involve detailed study technical and non-technical aspects. TPCL is carrying out technical studies with the help of TCE. The findings may be notified to the committee/commission. Apart from above listed difficulties, auto-reclosing may be considered for the 220 kV lines which do not involve cables.

2. OEM suppliers ABB and Siemens were invited to IIT Bombay on 26 April 2011 to discuss protection strategies of hybrid lines with the committee. Both presented their unique philosophy of protecting a hybrid line. ABB also suggested to carryout simulation studies of such equipments using RTDS or similar facility. It is worth mentioning that no such protection scheme is implemented in India. Still, the committee recommends that, with the help of OEM suppliers, a pilot project may be taken up for implementation of auto-reclosure on 220 kV hybrid lines in Mumbai System.
3. The current carrying capacity (thermal limit) of the short transmission lines and cables is different for various utilities. For all the short lines in the Mumbai region, the utilities should use appropriate formulae to determine these limits under various environmental conditions (ambient temperature, wind speeds etc.) as well as the age of the lines, and the condition of the peripheral equipment like joints/clamps, connectors, and other related hardware. The overall limit of a network branch is the minimum of the limits imposed by the line/ cable and its peripheral equipment. *Respective utilities are expected to work on preparing this data based on above mentioned criteria.* Using realistic limits as per the ambient conditions will ensure that the operators are not overly conservative during real-time operation. This data should be available to all system operators (load dispatchers) for all the short lines in the Mumbai region. For reference purpose the document published by Central Board of Irrigation and Power (CBIP) is attached in Annexure-I. This document describes capacity of line conductors in Amperes based on aging and ambient temperature.
4. On 26th April 2011, the Siemens also presented details of the equipment for dynamic calculation of the transmission line rating. It is worth mentioning that no such equipment is commissioned in India. However, the committee suggests that, the pilot project of implementing dynamic line rating should be taken up by the power supply utilities in Mumbai area.

5. If potential tripping of a transmission line can lead to overloads in other lines in the Mumbai region, all load dispatchers may be alerted. For this purpose, online contingency analysis may be carried out periodically. For example, if there are two lines in parallel, each of them should have some set values and all operators should be on "Alert Mode" if the line current on any line exceeds the set value. The following action is recommended: Check out if any relief in current flow can be obtained by either real (generator active power) power and reactive power scheduling (generator voltages, taps etc). Unfortunately, in the Mumbai system the amount of leverage on current flow by this rescheduling is not expected to be significant. Nonetheless the operators should explore possibilities for the same. *For sustained overload, utilities should take corrective actions depending up on the severity. All utilities may develop action-plan for corrective actions such as load trimming, special protection scheme (SPS), etc.* For reliable operation of such SPS, independent measurements at both ends of a line may be made for initiating SPS actions.
6. It is suggested that, in order to avoid unintended tripping of transmission lines, all utilities should internally recheck the relay configuration. Mainly, the overload signal should not be configured to trip the line, rather it should generate appropriate alarm signal. The Numerical Relays have an overload function with default "ON" settings. - All utilities are requested to recheck respective relays settings, particularly for "Overload" function.

2.3. Review on Islanding Schemes

The committee has come out with following suggestions and recommendations by discussing various aspects of islanding scheme.

1. Regarding the islanding scheme following issues may be revisited by WRPC:
    a. Mumbai islanding scheme has been devised considering a disturbance external to Mumbai system. Sanity checks may be done on the islanding and load shedding logic for situations where disturbances are within the TPCL/R-Infra network.
    b. UFR and df/dt load shedding in Mumbai system can start at slightly higher frequency than the present level of 48.0 Hz (may consider 48.4 Hz) considering that at NEW (NR, ER, NER, and WR grids) grid level such under frequency load shedding starts at 48.8 Hz. In case of any islanding of Mumbai system, TPCL and R-Infra should try to stay together as far as possible, forming a bigger island as further splitting has the potential to endanger both the subsystems.

c. R-Infra and TPCL should study the post-islanding automatic load restoration (in case of higher frequency) and load tripping scheme (in case of lower frequency) of each other.

2. The efficacy of prime mover controls under islanded conditions depends on actual parameters (gains, time constants, deadbands, limits etc). The utilities should explore if the model parameters, block diagrams and actual settings of their prime mover controllers can be obtained from the manufacturers, which can facilitate a simulation study. Either way primary response from generators becomes extremely important particularly in islanded mode of operation. Over frequency settings of the generators might also be checked to ensure that conservative settings are not adopted.
3. There is a case for "Better Situational Awareness" for a system operator both in terms of increased data rate and synchronized phasor information at various buses. Option of installing PMU as a pilot project can be explored for this purpose.

Chapter 3
Contingency Study on Mumbai Network

3.1. Introduction to Contingency Studies

Contingency study has been a very important step to get insight of network loading conditions in various possible scenarios. A deeper study can also help in finding out possible ways to get prepared for emergencies.

Contingency analysis covers a variety of analytical investigations performed by both system planners and operators. The system planner's objective is to identify the network elements that will be required to maintain system operation within planning criteria. The general requirement is to identify capital investments and operating costs for long term future developments. The system operator's objective is to identify the manner in which the system must be operated to maintain system security both in the near term (days, weeks, months) with existing network elements or the medium term (one to three years) during which a limited amount of equipment could be installed.

The basic approach to contingency analysis is to:

- Establish generation/demand base case scenarios that are to be tested.
- Identify variations of generation and demand for the base cases for the time period of development or operation.
- Identify the tests (contingencies) to be performed for both steady-state analysis and the system conditions that are acceptable or required prior to and during such contingencies. The tests and required post-contingency conditions are generally described by reliability criteria as discussed in coming sections.
- Perform the tests.

3.1.1. Security Testing Criteria for Contingency Analysis

The security testing criteria describe tests to be performed and required conditions prior to and during the test conditions. While there may be variations in criteria between electric power utilities, regions and countries, there is significant commonality.

Typical steady-state tests can include:

- Base case with all elements in service.
- Single contingencies (N-1). Loss of any transmission line or transformer or generator. These are often termed probable or credible contingencies.
- Double contingencies (N-2). Simultaneous loss of two single-circuit transmission lines, a double-circuit line or dc bipole. Variations on these contingencies exist worldwide specifically with respect to the definition of double circuit and the option of non-simultaneity of loss (N-1-1). These too are credible or probable contingencies.
- Less probable contingences and/or extreme contingencies can include loss of entire substations or multiple generators.

Such criteria are deterministic in the sense that the scenario being tested must comply with the acceptable system conditions or is considered to have failed the test. A failure implies the need for additional system elements (for planning) or an adjustment of pre-contingency test conditions (for operations). An overview of deterministic reliability tests is summarized in Table 2.

Table 2. Overview of Deterministic Security Test

Reliability Test Criteria for Network Augmentation or Transmission Expansion	**Test Condition**	**Analysis**	**Acceptable Conditions**
	Normal steady-state conditions	Steady-state power flow	System within normal loading and voltage limits
	Single contingencies (more probable)	Steady-state power flow	System within emergency loading and voltage limits immediately after outage and within normal limits after system adjustments
	Double contingencies (more probable)	Steady-state power flow	System within emergency loading and voltage limits after system adjustment
	Less probable contingencies	Steady-state analysis	No voltage collapse or overload cascading
	Extreme contingencies	Steady-state and Dynamic analysis	Avoidance of widespread load interruptions, uncontrolled cascading and blackouts

Following the disturbances in Mumbai system on 18th and 21st November 2010, MERC directed IIT Bombay to carryout study of N-1 compliance of transmission system in the Mumbai region. The committee decided to study the contingency in two phases,

1. Existing network as on the November 2010: This is useful for short-term findings and actions
2. Augmented (MERC approved) network for next 2 years: These findings will be useful to analyze augmented network with forecasted demand and generation in medium term (coming 2-3 years).

3.2. Current Load-Generation Balance in Mumbai

Mumbai experienced cumulative peak demand of 3130 MW in summer of 2010. The demand is met by following,

- TPCL generation : 1777 MW
- RInfra generation : 500 MW
- Import from MSETCL network: 853 MW

3.2.1. Existing Scenario

Present power generation scenario in Mumbai region is shown in Table 3.

Table 3. Present Power Generation in Mumbai

TPCL	Trombay unit 5	500 MW
	Trombay unit 6	500 MW
	Trombay unit 7A & 7B	180 MW
	Hydro - Bhira, Bhivapuri and Khopoli	447 MW
	Trombay unit 8, 250 MW (less 100 MW Merchant Generator Capacity)	150 MW
	TPC L Total	**1777 MW**
R-Infra	Dahanu Tharmal Power Station	500 MW
	R-Infra Total	**500 MW**
Mumbai Total		**2277 MW**

*Trombay, Unit 4, 150 MW is on standby mode.

Power demand scenario in Mumbai region is shown in Table 4.

Table 4. Present Power Handled by Mumbai Network

Demand	
On TPCL Network	2154 MW
On R-Infra Network	976 MW
Bilateral Purchase from inter and intra state	750 – 850 MW

In case of contingency of generating unit, power requirement is met through MSEDCL under agreement for supply of standby power and additional power purchases. This purchased power under open access is wheeled through MSETCL network to Mumbai area through EHV interconnections.

3.2.2. Interconnections of Mumbai area and MSETCL

The table below lists lines interconnecting Mumbai network with MSETCL and their average power flow in current situation.

Table 5. Interconnection Mumbai Power System with MSETCL

Sr. No	EHV interconnecting lines between MSETCL and Mumbai	Average flow pattern under loaded condition
1	220 KV Kalwa-Salsett D/C	324 MW
2	220 KV Borivali (MSETCL) – Borivali (TPCL)	442 MW
3	220 KV Trombay(MSETCL)-Trombay(TPCL) D/C	-262 MW
4	220 KV Boisar-Versova S/C	150 MW
5	220 KV Boisar - Dahanu S/C	-29 MW
6	110 KV Kalwa-Kalyan-Salsett D/C	40 MW

Sr. No	EHV interconnecting lines between MSETCL and Mumbai	Average flow pattern under loaded condition
7	110 KV Kalwa-Kalyan S/C	30 MW
8	2 x 200 MVA, 220/110 KV ICTs at Trombay (MSETCL)	162 MW
9	2 x 200 MVA, 220/110 KV ICTs at Borivali (MSETCL)	96 MW
10	MSEDCL load catered through TPCL network at Kalyan, Ambaranath, Salsett and Kolsett at 22 KV level	220 MW

3.3. N-1 Contingency Studies on Existing Network

3.3.1. Base Case Preparation

For preparing the base case, complete Maharashtra system network is simulated with prime focus on Mumbai system. Fig. 1 shows transmission system network and interconnection between various utilities in the Mumbai region.

The base case network for Mumbai system combines network database of all the three utilities supplying power to Mumbai, namely, MSETCL, TPCL, and R-Infra. For model validation purpose, the network components, generations and loading conditions are configured as per the condition of 18th November 2010. The validation of the model was done by comparing MW loading of various 220 kV transmission lines and ICTs, and Voltage level at important buses with those recorded on SCADA during the time of disturbance.

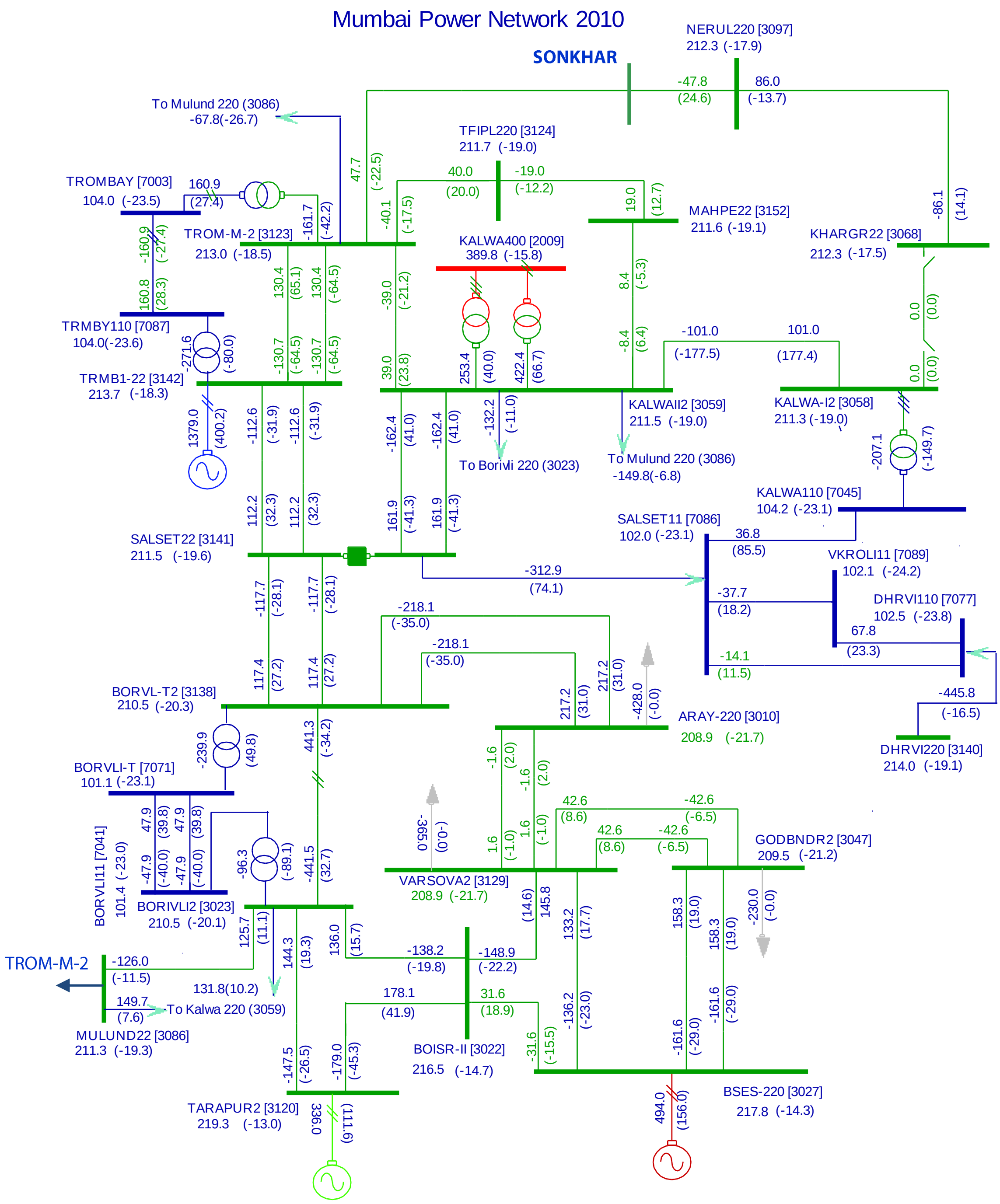

Fig. 1 Base case network of existing Mumbai system.

To prepare base cases for contingency studies of the Existing System, the network and loading conditions are modified as follows,

- All generating plants are running at full capacity (Ex-bus generation).

- Renewable energy generation (wind power) is shown as negative load at appropriate buses.
- Mumbai peak loading condition is adjusted to 3150 MW by proportionately increasing demand from various utilities. This was decided based on the historical demand met in Mumbai network as on 10th May 2010.
- Maharashtra network demand is set to its peak value so as to simulate the worst case scenario having simultaneous peak in Mumbai system and Maharashtra system. The total power generation of system is 16,107 MW, including 350 MW of wind generation. Total system demand is 15,453 MW with losses of 654 MW.

3.3.2. Generation of Scenarios and Outage Cases

The committee decided to simulate various contingency studies in four scenarios, forming the base cases as listed below,

Scenario 1: Salsette B/C: ON and Borivali-Borivali 220 kV Line: ON

Scenario 2: Salsette B/C: ON and Borivali-Borivali 220 kV Line: OFF (N-1)

Scenario 3: Salsette B/C: OFF and Borivali-Borivali 220 kV Line: ON (N-1)

Scenario 4: Salsette B/C: OFF and Borivali-Borivali 220 kV Line: OFF (N-1-1)

In each of the above mentioned scenarios, line outage and generator outages are studied as listed below,

Line outages

1. Trombay-Salsette 220 kV ckt 1out
2. Trombay-Salsette 220 kV ckt 1 and 2 out
3. Kalwa-Salsette 220 kV ckt 3 out
4. Kalwa-salsette 220 kV ckt 3 and 4 out
5. Dahanu – Ghodbundar 220 kV ckt 1out
6. Dahanu – Ghodbundar 220 kV ckt 1 and 2 out
7. Borivali-Salsette 220 kV ckt 1out
8. Borivali-Salsette 220 kV ckt 1&2 out
9. Borivali-Aarey 220 kV ckt 1 out
10. Boisar-Versova 220 kV ckt out

11. Boisar-Dahanu 220 kV ckt out
12. Dahanu-Varsova 220 kV ckt out
13. Borivali-Kalwa 220 kV ckt out

Generator outages

14. Dahunu Unit-1 is out
15. Trombay Unit-5 is out

The contingency studies are carried out by multiple run of load flow analysis with above mentioned scenarios and outages. Details of the studies and results are shown in Annexure – B. The Observations, Findings and Suggestions from the study are as follow,

1. It is observed that, irrespective of the Salsette Bus-Coupler position (On or Off), whenever the Borivali-Borivali 220 kV line is out of service, i.e., Scenario-2 and Scenario-4, the load flow solutions result into multiple corridors being overloaded heavily, leading to practically infeasible condition. This indicates that, with Borivali-Borivali 220 kV line out of service, Mumbai system may not be able to survive in peak loading condition. Further, the committee decided to study various outages only for Scenario-1 and Scenario-3 and subsequent suggestions/comments are related only to Scenario-1 and Scenario-3.
2. Studies show that, in case both the Aarey-Borivali 220 kV lines are out, the simulations do not converge indicating the infeasible situation for Mumbai system.
3. In almost all the studies, it is observed that, Aarey-Borivali 220 kV lines are carrying more than 200 MW per circuit, leaving little margin for further loading. Increased loading beyond 250 MW is presently controlled by load trimming scheme at R-Infra. It is suggested that, to cater peak demand in summer season, some of the Aarey load may be shifted to TPCL substations. Further feasibility studies may be carried out for this alternative.
4. Borivali-Borivali 220 kV line plays an important role in almost all events, and carrying substantial amount of power (generally in tune of 500 MW and above). Although, the current carrying capacity of the line is very high, the same is not true for associated in-feed lines including substation. It is recommended that these in-feed lines and substation equipments should be upgraded to handle higher loading.
5. It is observed from the studies that, outage of one of the two circuits of a double circuit line overloads the remaining line. However, rest of the network is marginally affected by the outage. In case both the lines are out, the situation deteriorates and couple of lines gets

overloaded. In any overloading condition, corrective actions by the respective utility should be initiated to avoid tripping.

6. Outage of any line on which power is imported to R-Infra network i.e., Boisar-Varsova 220 kV line (Ref. Annexure-II, Contingency-10), severely loads Aarey-Borivali lines.
7. In case of outage of one of the units of Dahanu power station (Ref. Annexure-II, Contingency-14), Aaray-Borivali 220 kV lines gets overloaded, getting feed mainly from Borivali-Borivali 220 kV line. Rest of the network is marginally affected. Further overloading situations can be controlled with the load shedding scheme at R-Infra.
8. In case of reduction of generation Trombay by 50 % (Ref. Annexure-II, Contingency-15), Kalwa ICT supports the system carrying more than 850 MW of power.

3.4. Short-term Remedial Measures

Following are the immediate actions/measure which can be taken up.

1. Current carrying capacity of all 220 kV transmission lines in the Mumbai region should be calculated base on the criteria mentioned in the interim-report and the same should be available to the operators for ready reference.
2. At all possible locations, option of auto-reclosure on 220 kV overhead line should be explored.
3. All relay configurations to be rechecked by respective utilities for avoiding overload tripping and configure the same for Alarm signal.
4. The alternative of load shedding at higher frequency than the present setting of 48.0 Hz can be discussed.
5. Alternative of shifting Aarey load to TPCL substation should be explored by the utilities to marginally relieve Aarey-Borivali 220 kV line loading.
6. High reliability SPS for automatic load shedding in case of network overloading or tripping must be commissioned on priority to avoid cascading failures.

3.5. Experimental Trombay (TPCL) – Saki (R-Infra) Connection

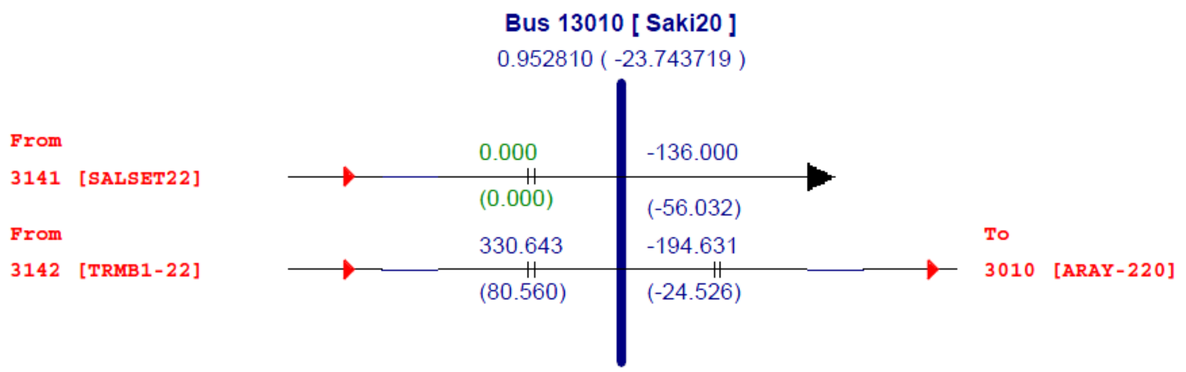

Fig. 2 Trombay (TPCL) – Saki (R-Infra) Connectivity to Relieve Critical Loading of Aarey- Borivali Lines.

R-Infra and subsequently IIT Bombay (on recommendation of committee members) experimented a new 220 kV double circuit connectivity between Trombay (TPCL) and Saki (R-Infra) in the existing network. The graphical representation of this connectivity is shown in Fig. 2.

During this study all network conditions and parameters are set to replicate the base case discussed in 3.3.1. Important observations from the simulation study are as follows,

- Power flow on Aarey- Borivali 220 kV ckt reduces to 128.2 MW in the new scenario as compared to its loading over 218 MW in base case (Ref. Fig. 1).
- Line loading of Bo-Bo 220 kV line reduces from 441 MW to 377 MW.
- Rest of the network is within their operating limits.

The committee recommends that, the Commission may direct utilities to further investigate feasibility of the 220 kV double ckt connections between Trombay (TPCL) – Saki (R-Infra). This connection will help relieving existing system from the critical loading, particularly during peak conditions before network augmentation takes place.

3.6. Summary of Contingency Studies on Existing Network

In general, the committee has observed that, existing Mumbai network is quite fragile. This can be observed from the fact that for Scenario-2 and Scenario-4 base cases without any contingency, multiple lines in the network are overloaded. In view of this, it is envisaged that, network strengthening should be taken up on the higher priority.

Chapter 4

Load Growth, Network Augmentation and Contingency Studies

4.1. Introduction

Mumbai has already seen a demand of 3130 MW in summer of 2010 and is expected to see a demand of approximately 5000 MW by the year 2014-2015. New power plants cannot come in Mumbai regions due to unavailability of land for power generation purpose. The only way left is to bring power from outside to the existing Mumbai system.

This chapter presents study of augmented network coming up by end of the financial year 2012-13. For this purpose all the MERC approved transmission projects of R-Infra and TPCL are added in the existing network. Moreover, augmentation and upgradation of MSETCL network near Mumbai region is also considered in the studies. Further sections details about utility wise MERC approved projects, load growth, and N-1 contingency analysis of Mumbai system for the year 2012-13.

4.1.1. Network augmentation of R-Infra by the year 2012-13

Table 6 shows list of project approved by MERC for transmission network augmentation of R-Infra in the coming two years.

Table 6. MERC Approved List of Project for R-Infra

Sr. No.	MERC Approved list of projects
1	220kV GIS Chembur from Trombay (MSETCL)
2	220kV GIS at Saki EHV Station from Aarey (R-Infra)
3	220kV GIS Borivali (MSETCL Borivali – R-Infra Borivali)
4	220kV Nagari niwara (LILO MSETCL Borivali – R-Infra Aarey)

5	220kV Goregaon EHV station (LILO of Varsova - Aarey)
6	Gorai 220 kV station (LILO of Ghodbunder – Versova 220 kV and connectivity from Borivali, MSETCL)
7	Dahisar 200 kV station (from Ghodbunder 220 kV station)
8	LILO existing MSETCL Boisar-Borivali 220 kV line at Ghodbunder EHV Stn

4.1.2. Network augmentation of TPCL by the year 2012-13

Table 7 shows list of project approved by MERC for transmission network augmentation of TPCL in the coming two years time span.

Table 7. MERC Approved List of Project for TPCL

Sr. No.	MERC Approved list of projects
1	Proposed 220 kV Trombay-Dharavi-Salsette Lines Project
2	Establishing 220kV GIS Receiving Station at Mahalaxmi from Dharavi (T)
3	Establishing 220 kV GIS at SAKI & Upgrading of Transmission lines
4	220kV interconnection with MSETCL at Borivali
5	245 kV GIS at SAHAR (Airport) from Saki 220
6	220 kV Kalwa Salsette third line between MSETCL (KALWA) and TATA Power Salsette R/S with line bays at both the ends.

4.1.3. MSETCL Network augmentation around Mumbai by the year 2012-13

The network augmentation in MSETCL consists of conversion of existing 220 KV corridor from Kharghar-Boisar with High Ampacity conductor and strengthening of this corridor as shown in Fig. 3. This includes,

- Conversion of 220 kV Kharghar – Kalwa – Borivali – Boisar D/c line with 220 kV 525 sq mm AAAC Twin Conductor
- 220 kV Kharghar – Borivali - Boisar D/c line with 220 kV 525 sq mm AAAC Twin Conductor

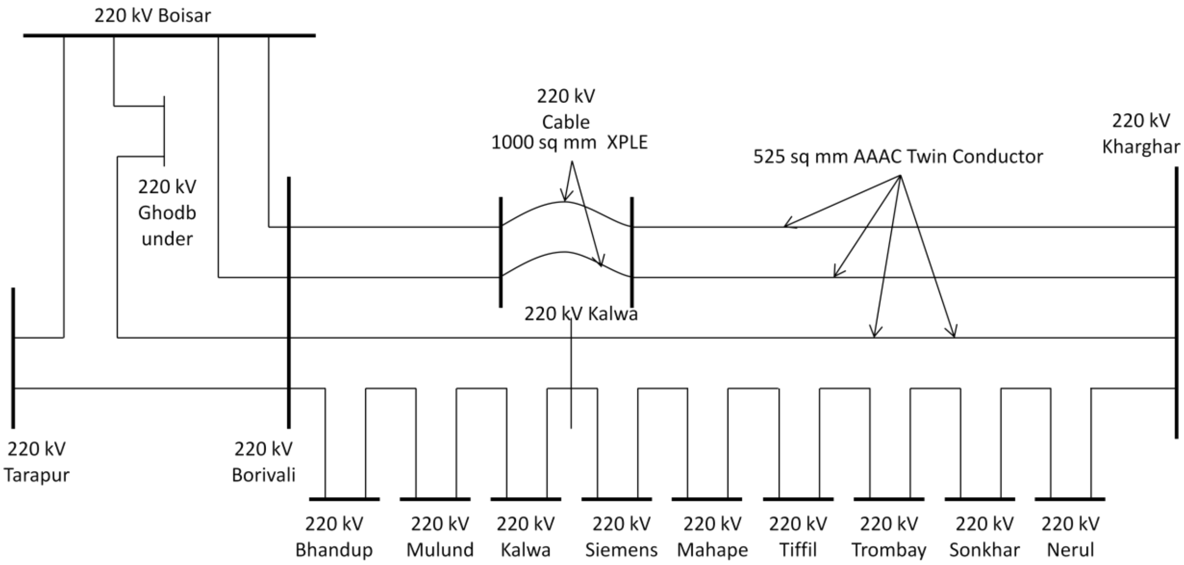

Fig. 3 Upgaradation of Kharghar – Borivali 220 kV corridor.

4.2. N-1 Contingency Studies on Augmented Network

4.2.1. Base Case Preparation

Base case network is formed by adding MERC approved infrastructure as mentioned in 4.1.1, 4.1.2 and 4.1.3 (transmission lines, transformers, etc.) on top of the existing network. By the year 2012-13 Mumbai is expected to see a peak demand of 4149 MW. The additional load growth is adjusted at various drawal points in TPCL and R-Infra network. However, loading conditions of rest of the Maharashtra system is not altered. Details of the loading on various utilities are shown in Table 8.

Table 8. Base Loading Conditions with Augmented Network

Utility	Load
On TPCL network	2690 MW
On R-Infra network	1459 MW
Total	4149 MW

Fig. 4 shows transmission augmented network of Mumbai power system.

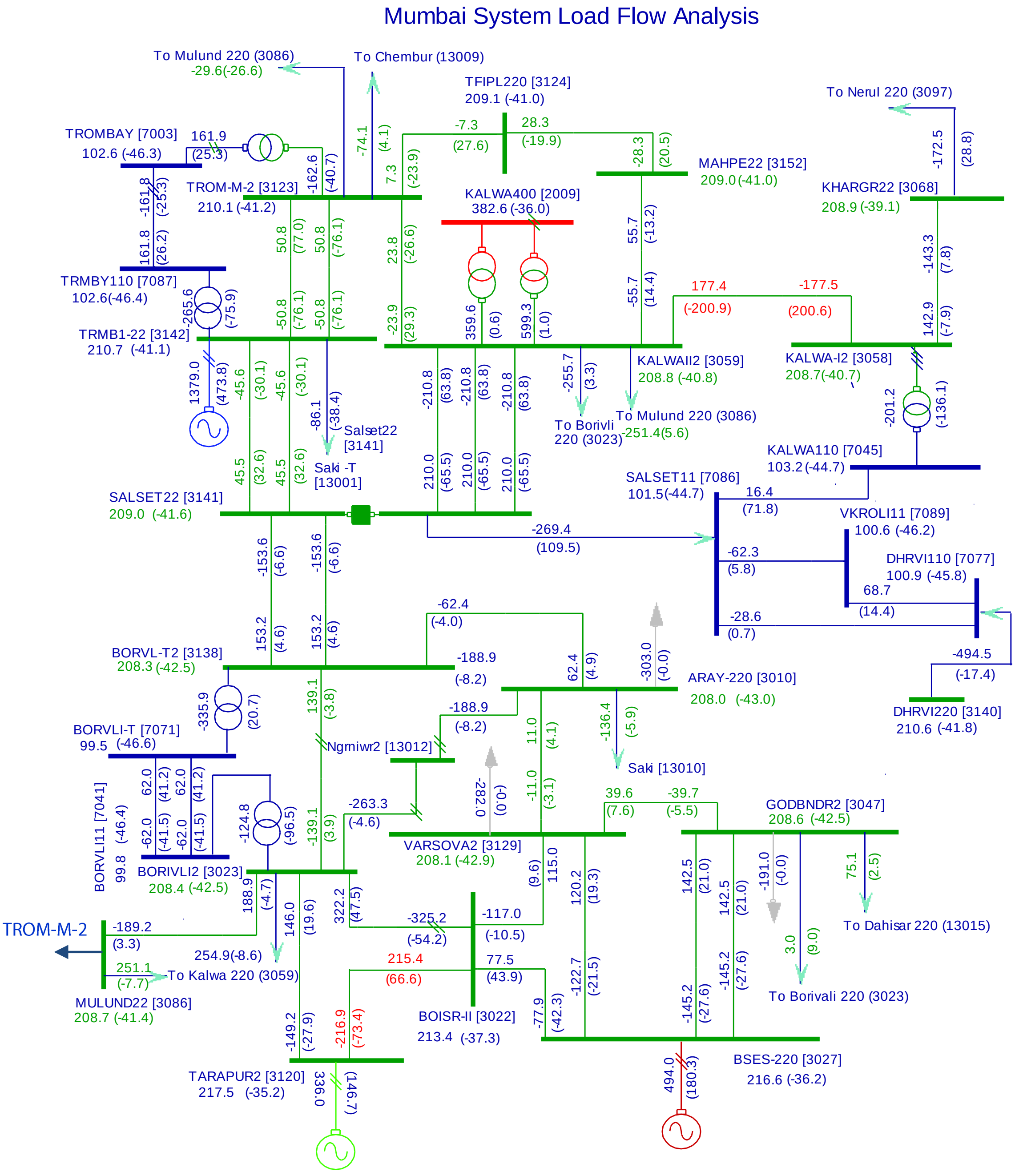

Fig. 4 Base of Augmented Mumbai System for the Year 2012-13.

4.2.2. Outage Scenarios

It is anticipated that, all the components will be in service for the base case studies. Accordingly, the committee decided to simulate various contingency studies on the base case. Various line outage and generator outages are performed as listed below,

Line outages

1. Trombay-Salsette 220 kV ckt 1out
2. Trombay-Salsette 220 kV ckt 1 and 2 out
3. Kalwa-Salsette 220 kV ckt 3 out
4. Kalwa-salsette 220 kV ckt 3 and 4 out
5. Dahanu – Ghodbundar 220 kV ckt 1out
6. Dahanu – Ghodbundar 220 kV ckt 1 and 2 out
7. Borivali-Salsette 220 kV ckt 1out
8. Borivali-Salsette 220 kV ckt 1&2 out
9. Boisar – Broivali ckt1&2
10. Borivali-Aarey 220 kV ckt 1 out
11. Boisar-Versova 220 kV ckt out
12. Boisar-Dahanu 220 kV ckt out
13. Dahanu-Varsova 220 kV ckt out
14. Borivali-Kalwa 220 kV ckt out
15. Bo-Bo corridor outage

Generator outages

16. Dahunu: 250 MW Outage
17. Trombay: 500 MW Outage

4.3. Findings of Contingency Studies on Augmented Network

Details of the system study and their results are shown in Annexure – C. General finding and comments on the analysis of the augmented network are as follows,

- The augmented base case network of the year 2013 has no overloads on the lines. In the studies, BO-BO line is considered as available. The studies indicate that the bus-coupler at Salsett does not play any important role and it's on or off position do not affect results significantly.
- If all elements of the augmented network as per MERC sanction are energized within expected time frame in 2013, the augmented network should be able to withstand most of the N-1 line outage contingencies without threat to security as per the results with exception of few. This is with the assumption that the network is fully connected. However, the network may have to be split to contain the fault level. Splitting will reduce the security of the system. The committee recommends separate studies to be carried out for these conditions.
- Outage of two parallel circuits (N-2) certainly overloads the third parallel line exceeding the overload limit.
- In absence of new generation availability in Mumbai regions, the additional load is supplied mainly through Kalwa, Boisar, and Borivali points. It should be noted that the increasing interconnection at 220 kV also increases fault level (e.g., Kalwa substation). It is recommended that possibility of bus-split should be explored by the respective utilities at all such substations. In order to further contain the fault level and conserve ROW (which is a very serious problem in Mumbai region), future upgrades can consider 400 kV substations.
- In several cases it is observed that Tarapur-Boisar single ckt line operates near to its loading limit. This problem might increase if one also considers the 220 kV interconnection between Tarapur and GETCO systems.
- Inter-connector at Kalwa substation at 220 kV level is found to exchange heavy amount of reactive power. The committee recommends that STU may look for the solution.
- However, the generation outages are the most severe. Any outage of generation in Mumbai region does not converge the simulation until some generation is added

locally (say at Kalwa). Some generation source i.e., either 400kV interconnection or HVDC input is required in Mumbai as addition in generating capacity is not planned in Mumbai. It is to be noted that, additional source at Kalwa only helps in solving loadflow case. This indicates additional generation requirement in coming years in Mumbai system. If not physically located generation, extra power must be brought to the Mumbai network by any means to cater the load growth.

4.4. Comparison of flow pattern on important lines and ICTs in existing and augmented network

Power flow pattern change is observed in existing and augmented cases of Mumbai network. These changes are mainly due to network augmentation along with serving 4149 MW of load. While comparing base cases of both the situations, following observations are made. The Table 9 will help us to understand how the additional demand is met in new scenario.

Table 9. Power Flow Pattern Comparison: Existing vs Augmented Network

Particular	Existing Case	Augmented Case
Kalwa ICT (MSETCL)	675	959
Kalwa – Salsette corridor	324	630
Borivali (MSETCL) – Nagri niwara (R-Infra)	---	262
Borivali (MSETCL) – Borivali (R-Infra)	---	216
Borivali (MSETCL) – Gorai	---	161
Borivali (MSETCL) – Dahisar	---	75
Boisar (MSETCL) – Borivali corridor	138	325
Bo – Bo line corridor	441	139
Borivali (TPCL) – Aarey (R-Infra)	218	62

Chapter 5

Study of 400 kV HVAC and VSC Based HVDC by MSETCL

5.1. Network Augmentation and System Study

Mumbai is expected to face peak loading of 5000 MW by the year 2014.15. Certainly, this load growth cannot be supplied by the existing generation available in the Mumbai and nearby region. Since the possibility of new generation near Mumbai is nil, we need to explore alternatives of brining external power to Mumbai system using HVAC and/or HVDC lines.

This chapter expresses prospective of load growth in Mumbai region for next years. Further sections will explore possibilities of bringing power to Mumbai system using 400 kV AC lines and VSC based HVDC[1]options along with expected load growth in the Mumbai system.

5.1.1. Load growth in Mumbai Power System

Table 1shows estimated load growth in Mumbai system for coming years.

Table 10. Expected Load Growth in Mumbai for Next Five Years

Year	Expected Peak Demand in Mumbai (MW)			Generation capacity in Mumbai (MW)	Load-Generation Gap (MW)
	R-Infra	TPCL + Best	Total		
2010-11	976	2154	3130	2277	-853
2011-12	1109	2233	3342	2277	-1065

[1] The information, data, and analysis of 400 kV and VSC based HVDCt presented in the chapter are based on the studies conducted at MSETCL (STU). The committee has only expressed its opinion on the findings of MSETCL.

Year	Expected Peak Demand in Mumbai (MW)			Generation capacity in Mumbai (MW)	Load-Generation Gap (MW)
	R-Infra	TPCL + Best	Total		
2012-13	1221	2350	3571	2277	-1294
2013-14	1343	2474	3817	2277	-1540
2014-15	1468	2706	4174	2277	-1897

* Load-Generation Gap of Mumbai would be met from the bilateral power purchase.

In addition to above load growth to identified triggering loads are expected as mentioned in Table 11.

Table 11. Triggering Load

Development of commercial complex in Airport area	80 MW
Rehabilitation slum in Airport area by HDIL	60 MW
Development of Commercial complex in Godrej Vikhroli area and vertical load development in other area	200 MW
Development of Kohinur city, Neelkanth gammon, Vidhyvihar containers, Bhandari Estate, Swan Mill and Sahakar Nagar in Kurla area	125 MW
Total triggering load	**465 MW**

Above load growth and addition due to triggering loads needs to be considered for planning Mumbai system grid for FY 2014-15. Moreover, about 230-250 MW load of MSEDCL in Kalyan, Ambarnath, Salsett and Kolsett area is fed through TPCL EHV net work, which is expected to increase to 330 MW by 2014-15. This clearly indicates that transmission system network for Mumbai needs to be planned to cater about 5000 MW loads by FY 2014-15.

5.2. Major Transmission Bottlenecks in Bringing Power to Mumbai

The simulation studies on existing network of Mumbai show that, during contingencies, the transmission lines in Mumbai region will continue to remain critically loaded till proposed transmission lines are commissioned. This hints about network augmentation to cater the increasing demand in coming years. The studies also showed that the network augmentation will solve the issues pertaining to line loading. However, the problem is half solved. Addition of new generation is equally important to supply the new demand. And this is the bigger challenge, particularly due to land unavailability within or near Mumbai area.

Since no generation can be added physically near to Mumbai area, the option left is to transfer power from outside Mumbai to the inside Mumbai using HVAC (400 kV AC) and HVDC lines. In evaluating this, below are the bottlenecks identified.

1. Limited interconnection with MSETCL's Network, only at Borivali, Kalwa, and Boisar on 220 KV level, putting strain on 220 KV network.
2. Non availability of 400 kV and above voltage level transmission network in Mumbai.
3. Right of Way (RoW) and substation space constraints.
4. Less Generation availability in Mumbai region.

5.2.1. Future Load Generation Balance for Mumbai area.

As regards with the addition of generation capacity in Mumbai, there are no plans in pipe line to set up generating stations in Mumbai area due to space constraints and environmental restrictions[2]. The generation availability for Mumbai is going to remain as 2277 MW by FY 2014-15. This is the major aspect considered for strengthening Mumbai interconnections with MSETCL grid. Hence, it is clear that 2000 – 2500 MW availability has to be mitigated from outside Mumbai.

In view of above following additional interconnections are planned.

- 400 KV Vikhroli (Ghatkopar) sub-station (TPCL)
- +/- 150 KV, 700 MW VSC based HVDC . (R-Infra)
- 400/220 KV Ghodbundar S/S (R-Infra)

Alternate connectivity for bringing power to Mumbai is as follows,

[2] TPCL, Dehran plant is planned in the vicinity of Mumbai

I) 400 KV Vikhroli (TPC)

i. 400/220/33 kV, 3x500 MVA Transformer at 400 kV Vikhroli S/s
ii. 400 KV Kharghar(MSETCL)-Vikhroli S/C line.
iii. 400 KV Marve(TPC)-Vikhroli D/C line.(DPR not submitted)
iv. 400 KV Navi Mumbai(PG)-Vikhroli S/C line

a) 220 KV line from 400 KV Vikhroli – Vikhroli (East) D/c line
b) 220 KV line from 400 KV Vikhroli – Vikhroli (West) D/c line
c) LILO on 220 KV Trombay-Salsette-Saki line at 400 KV Vikhroli
d) LILO on 220 kV Trombay (MSETCL)-Mulund line at 400 KV Vikhroli

II) $\pm$150 KV, 2x350 MW Bipole HVDC Link between 400 KV Nagothane and 220KV Aarey S/S.

III) 400 KV Ghodbunder (R-Infra).

a) 400/220 KV, 3 x 600 MVA ICT at 400 kV Ghodbunder S/s.
b) 400 KV Kudus-Ghodbunder D/C line.
c) 400 KV Boisar(PG)-Ghodbunder D/C line.
d) 220 KV Line from 400 KV Ghodbunder to 220 KV Ghodbunder.
e) 220 KV 400 KV Ghodbunder – Dahisar D/c line

5.2.2. +/- 150 kV, 700 MW VSC based HVDC with 400 MVaR Filters

Presently, 500 MW generation at Dahanu (R-Infra) and about 100 MW import from Boiser is consumed in 220 KV Varsova and Ghodbundar Sub stations. R-Infra has proposed HVDC connectivity of Mumbai area with proposed +/- 150 KV, 700 MW VSC based HVDC between existing Aarey S/s and MSETCL's 400/220 KV Nagothane S/s. This will take care of importing additional 700 MW power to Mumbai network.

Complete load of Aarey and some import to Ghodbundar is met through 220 KV Borivali-Aarey D/C lines and in turn this power is coming from 220 KV Kalwa-Salsett D/C, 220 KV Trombay-Salsett D/C and 220 KV Salsett- Borivali lines corridor, which is loaded always to full capacity. Any contingency in this corridor results in alert situation. Hence, injection at 220 KV Aarey substation is required to maintain loading of lines to comfortable level.

Following facts are considered while planning HVDC at Aarey substation.

- Power flow on HVDC link is controllable as per system requirement, which is not possible with AC interconnection.
- The HVDC connectivity will offer limited support only. In case of tripping of all AC lines, there is possibility of losing the HVDC due to extremely high or low frequency in the island. However, the HVDC has black-start capability in case of complete blackout. It can play a limited role in quickly ramping up the power order whenever the parallel AC network gets depleted.
- In the event of loosing AC interconnection due to localized fault at say Kalwa, Borivali or Trombay, HVDC shall continue to support Mumbai grid from Nagothane where strong support from RGPPL Dabhol Power station is available.
- In view of proposed new sub stations in North Mumbai which are having connectivity on 220 KV cable admeasuring about 200 Km length requires reactive compensation. HVDC system along with filters of 400 MVaR at convertor station end automatically compensates this requirement.

5.2.3. Proposed Network Augmentation in Mumbai Area for Next Five Years

The load flow study performed by MSETCL considers network augmentation for next five years along with respective load growth. Table 12 and Table 13 show existing and proposed network and respective load growth in R-Infra and TPCL respectively.

Table 12. (R-Infra) Existing Mumbai Network and Proposed Network as per STU 5 Year Plan for the year 2010-11 to 2014-15

Sr. No.	**Name of S/s**	**Voltage level**	**Trans. Capacity in MVA**	**Load in MW**				
				2009-10	**2010-11**	**2011-12**	**2012-13**	**2013-14**
Existing S/s								
1	Aarey	220/33	525	401	343	269	179	179
2	Versova	220/33	525	336	268	282	291	299
3	Ghodbunder	220/33	425	241	264	191	162	177
	TOTAL		1475	978	875	742	632	655
Proposed S/s								
1	Saki	220/33	250	-	95	136	145	167
2	Goregaon	220/33	250	-	81	113	119	123
3	Chembur	220/33	250	-	-	74	103	107
4	Borivali	220/33	250	-	-	64	91	91
5	Gorai	220/33	250	-	-	89	119	95
6	Airport	220/33	250	-	-	-	132	120

Sr. No.	Name of S/s	Voltage level	Trans. Capacity in MVA	Load in MW				
				2009-10	**2010-11**	**2011-12**	**2012-13**	**2013-14**
7	Dahisar	220/33	250	-	-	-	47	75
8	Nagri Niwara	220/33	250	-	-	-	32	74
9	Drive In Theater, Bandra(E)	220/33	250	-	-	-	92	162
10	Golibar	220/33	250	-	-	-	-	34
11	Mankhurd	220/33	250	-	-	-	-	91
12	KIE	220/33	250	-	-	-	-	117
13	Kurla	220/33	250	-	-	-	-	33
	TOTAL		3250	0	176	476	880	1289
	TOTAL (Ex + Prop)		**4725**	**978**	**1051**	**1218**	**1512**	**1944**

Table 13. (TPC) Existing Mumbai Network and Proposed Network as per STU 5 Year Plan for the year 2010-11 to 2014-15

Sr. No.	Name of S/s	Voltage level	Trans. Capacity in MVA	Load in MW				
				2009-10	2010-11	2011-12	2012-13	2013-14
Existing S/s								
1	Ambernath	110/22	150	35	37	37	40	43
2	Backbay	220/110	500	104	110	120	129	139
3	Borivali	110/22	210	143	152	165	177	190
		220/33	750	83	88	96	113	121
4	Carnac	110/22	165	65	69	75	81	87
		110/33	180	100	106	116	124	133
		220/33	630	223	237	258	277	297
5	Chembur	110/11	418.5	101	107	97	104	112
		110/22						
6	Dharavi	110/22	390	207	220	168	180	173
		110/33	150	240	255	278	268	257

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<tr><td>14</td><td>Salsette</td><td>220/22</td><td>750</td><td>90</td><td>96</td><td>74</td><td>80</td><td>85</td></tr>
</table>

Sr. No.	Name of S/s	Voltage level	Trans. Capacity in MVA	Load in MW				
				2009-10	2010-11	2011-12	2012-13	2013-14
15	Versova	110/33	270	85	90	98	105	113
16	Vikhroli	110/22	315	120	128	129	138	148
17	Trombay	110/22	196	100	106	116	124	133
	TOTAL		**8779.5**	**2418**	**2569**	**2633**	**2780**	**2977**
Proposed S/s								
1	Hiranandani	110/33	180	-	-	55	60	65
2	BKC	110/33	180	-	-	50	76	81
3	Sahar (Airport)	220/33	250	-	-	60	70	80
4	HDIL Kurla	110/33	180	-	-	-	-	50
5	Antop Hill (Wadala)	220/33	250	-	-	-	35	40
6	Vikhroli (West)	220/33	250	-	-	-	-	50
7	Chunabhatti	220/33	250	-	-	-	-	20

Sr. No.	Name of S/s	Voltage level	Trans. Capacity in MVA	Load in MW				
				2009-10	2010-11	2011-12	2012-13	2013-14
8	Ghatkopar	400/220	1000	-	-	-	-	-
	TOTAL		**2540**	**0**	**0**	**165**	**241**	**386**
	NET TOTAL (EX+ PROP)		**11319.5**	**2418**	**2569**	**2798**	**3021**	**3363**

5.2.4. Load Flow Study Results

Load flow studies are carried out by MSETCL considering EHV network planned by FY 2013-14 in Mumbai area. While carrying out Load flow study the substation wise projected load for existing as well as proposed substation is considered. Proposed interconnections as well as strengthening of existing MSETCL corridor is also considered for the purpose of study.

- From load flow of existing network it is observed that 220 KV Kalwa-Salsett, Salsett-Borivali and Borivali-Aarey corridor are critically loaded.
- In first three cases case-I, Case-II and Case-III, load flow study for individual proposed interconnections are considered one by one keeping other two interconnections off.
- In Case-IV, 400 KV Vikroli and 400 KV Ghodbundar without HVDC link is considered
- In Case-V, all the three proposed interconnections are considered.

The findings of the case studies are detailed in Table 14. The comparative analysis of all the cases is summarized in Table 15.

Table 14. Case Studies of Various Cases for HVAC (400 kV) and HVDC Network

Sr. No.	Case No.	Proposed Interconnections	Additional Support to Mumbai System		Constraints in transmission network		Remark
			MW	Source	Name of Line	MW	
1	Case 1	400 KV Vikroli	716	400/220 KV ICT at Vikroli	220 KV Kalwa-Salsett D/C	466	In this case 1666 MW support is obtained from out side, while constraints on lines are as indicated
			950	From MSETCL Borivali 220 KV	220 KV Salsett-Borivali D/C(TPC)	390	
			1666		220 KV Borivali (TPC) - Aarey D/C	296	
					220 KV Borivali (MSETCL) - Gorai S/C	154	
					220 KV Drive In - Chembur D/C	426	
					220 KV Tromaby(MSETCL) - Chembur D/C	370	
					220 KV Salsett - Airport S/C	182	
					220 KV Tromaby(TPC) -Saki	180	

Sr. No.	Case No.	Proposed Interconnections	Additional Support to Mumbai System		Constraints in transmission network		Remark
			MW	Source	Name of Line	MW	
2	Case 2	+/- 150 KV, 700 MW Nagothane-Aarey HVDC Link	700	HVDC Link	220 KV Kalwa-Salsett D/C	540	In this case 1540 MW support is obtained from out side, while constraints on lines are as indicated
			840	From MSETCL Borivali 220 KV	220 KV Salsett - Airport S/C	190	
			1540		220 KV Tromaby(TPC) -Saki	173	
					220 KV Tromaby(MSETCL) - Chembur D/C	332	

Sr. No.	Case No.	Proposed Interconnections	Additional Support to Mumbai System		Constraints in transmission network		Remark
			MW	Source	Name of Line	MW	
3	Case 3	400 KV Ghodbundar	1000	400/220 ICTs at Ghodbundar	220 KV Kalwa-Salsett D/C	490	In this case 1701 MW support is obtained from out side, while constraints on lines are as indicated
			701	From MSETCL Borivali 220 KV	220 KV Salsett - Airport S/C	193	
			1701		220 KV Tromaby(TPC) -Saki	170	

Sr. No.	Case No.	Proposed Interconnections	Additional Support to Mumbai System		Constraints in transmission network		Remark
			MW	Source	Name of Line	MW	
					220 KV Tromaby(MSETCL) - Chembur D/C	340	
					220 KV Borivali (TPC) - Aarey D/C	302	
					220 KV Ghodbundar-Varsova S/C	200	
					220 KV Ghodbundar - Gorai S/C	254	
					220 KV Ghodbundar - Dahisar D/C	398	
					220 KV Dahisar - Borivali (R-Infra) D/C	320	
					220 KV Borivali (R-Infra) - Borivali (TPC) D/C	304	
4	Case 4	400 KV Vikroli and	589	400/220 KV ICT at	220 KV Kalwa-Salsett D/C	326	In this case 2132 MW

Sr. No.	Case No.	Proposed Interconnections	Additional Support to Mumbai System		Constraints in transmission network		Remark
			MW	Source	Name of Line	MW	
		400 KV Ghodbundar		Vikroli			support is obtained from out side, while constraints on lines are as indicated
			891	400/220 ICTs at Ghodbundar	220 KV Salsett - Airport S/C	187	
			652	From MSETCL Borivali 220 KV	220 KV Tromaby(TPC) -Saki	175	
			2132		220 KV Tromaby(MSETCL) - Chembur D/C	298	
					220 KV Drive In - Chembur D/C	304	
					220 KV Ghodbundar-Varsova S/C	178	
					220 KV Ghodbundar - Gorai S/C	231	
					220 KV Ghodbundar - Dahisar D/C	346	
					220 KV Borivali (TPC) - Aarey D/C	290	

Sr. No.	Case No.	Proposed Interconnections	Additional Support to Mumbai System		Constraints in transmission network		Remark
			MW	Source	Name of Line	MW	
5	Case 5	400 KV Vikroli, +/- 150 KV 700 MW Nagotahne-Aarey HVDC Link and 400 KV Ghodbundar	512	400/220 KV ICT at Vikroli	220 KV Salsett - Airport S/C	190	In this case 2299 MW support is obtained, while there are no constraints on grid lines and constraints as indiacted are on radial lines only.
			700	HVDC Link	220 KV Tromaby(TPC) -Saki (TPC)	173	
			731	400/220 ICTs at Ghodbundar	220 KV Ghodbundar - Gorai S/C	186	
			356	From MSETCL Borivali 220 KV	220 KV Ghodbundar - Dahisar D/C	296	
			2299				

Table 15. Comparative Study of Various Cases of Network Augmentation

Sr. No.	**Lines**	**CASE-I** **With** **400 kV Vikhroli**	**CASE-II** **With** **700 MW Nagothane - Aarey HVDC Link**	**CASE-III** **With** **400 kV Ghodbunder**	**CASE-IV** **With** **400 kV Vikhroli and 400 kV Ghodbunder**	**CASE-V** **With** **400 kV Vikhroli, 700 MW Nagothane - Aarey HVDC Link and** **400 kV Ghodbunder**
		Flow in MW				
1	220 KV Kalwa-Salsett D/C	466	540	490	326	230
2	220 KV Salsett-Borivali D/C(TPC)	390	140	62	170	46
3	220 KV Borivali (TPC) - Aarey D/C	296	40	302	290	18
4	220 KV Borivali (MSETCL) - Gorai S/C	154	123	67	72	50
5	220 KV Chembur - Drive In D/C	426	200	222	304	170
6	220 KV Tromaby(MSETCL) – Chembur D/C	370	332	340	298	220
7	220 KV Salsett - Airport S/C	182	190	193	187	190

Sr. No.	Lines	CASE-I With 400 kV Vikhroli	CASE-II With 700 MW Nagothane - Aarey HVDC Link	CASE-III With 400 kV Ghodbunder	CASE-IV With 400 kV Vikhroli and 400 kV Ghodbunder	CASE-V With 400 kV Vikhroli, 700 MW Nagothane - Aarey HVDC Link and 400 kV Ghodbunder
		Flow in MW				
8	220 KV Tromaby(TPC) –Saki S/C	180	173	170	175	173
9	220 KV Ghodbundar-Varsova S/C	69	40	200	178	119
10	220 KV Ghodbundar - Gorai S/C	92	79	254	231	186
11	220 KV Ghodbundar - Dahisar D/C	12	30	398	346	296
12	220 KV Dahisar - Borivali (R-Infra) D/C	64	46	320	272	220
13	220 KV Borivali (R-Infra) - Borivali (TPC) D/C	240	224	304	194	122
14	Import to Mumbai Network	1666	1540	1700	2132	2300

5.3. Summary of Analysis of 400 kV HVAC and 150 kV HVDC Alternatives

It is expected that by the year 2014-15 Mumbai power system will have to be prepared for peak load of 5000 MW. Existing 220 kV network is unable to handle peak demand of 5000 MW. To match the increasing demand, the STU has already planned 400 kV network by the year 2013-14. It should also be noted that, the increasing demand cannot be supplied with the existing generation availability due to constraints of the existing network of bringing extra power to Mumbai. Bringing power on HVAC and HVDC lines to Mumbai will act as virtual generator which Mumbai desperately needs.

To analyze various alternative of 400 kV HVAC and 150 kV VSC based HVDC , various cases have been considered, namely case 1 to case 5. The cases present phased manner inclusion of various alternative considered, viz., 400 kV Vikhroli, 400 kV Ghodbunder, and VSC based HVDC . It can be observed from the analysis that Case 5, which includes all the three alternatives, is the most suitable network configuration to supply the estimated load growth in coming years. In this case Mumbai gets external support of 2299 MW. Moreover, in this scenario no important line is getting overloaded with exception of few radial lines being overloaded.

It is important that to cater to future load growth of Mumbai network additional (implicit) generation using HVAC and HVDC is highly important. Therefore, connectivity at 400 kV using Vikhroli (TPCL) and Ghodbunder (R-Infra) needs to be taken up at higher priority.

Chapter 6
Recommendations

6.1. Recommendations on Protection and Islanding Schemes

6.1.1. Protection Scheme

- The committee suggests that single phase auto-reclosure might be implemented immediately for all overhead lines in Mumbai system. In respect of such lines emanating from generating stations, the studies on the effect of such auto-reclosure on turbine-generator (TG) shaft being carried out by the Mumbai utilities might be completed at the earliest. (notwithstanding the fact that many other generating stations in the country have kept this feature in service). For auto-reclosure on hybrid lines the committee strongly recommends a pilot project might be taken up by the utilities in Mumbai in collaboration with relay manufacturers.
- A separate pilot project on dynamic line rating needs to be taken up on very important corridor on experimental basis.
- Routine checks should be carried out at regular intervals to check configuration of relays. Reconfiguration of Alert and Trip mode of relays on account of overload may be needed at some places.
- SPS providing automatic correction for network overloads or depletion needs to be commissioned by all utilities in Mumbai in a coordinated fashion. SLDC Kalwa to take the lead in this direction. Considering the state of the Mumbai network, it is important that such SPS might be made reliable through redundant measurements as well as duplication of equipment.

6.1.2. Islanding Scheme

- UFR and df/dt load shedding in Mumbai system can start at slightly higher frequency than the present level of 48.0 Hz (may consider 48.4 Hz). In case of any islanding of Mumbai system, TPCL and R-Infra should try to stay together as far as possible, forming a bigger island.

- Primary response from generating units and automatic under frequency based load shedding are crucial to the survival of any island formed. The under frequency and over frequency settings of generators might be checked to ensure that a conservative setting leading to unit tripping does not jeopardize the island further. Rate of change of frequency based load shedding with the settings based on studies will be more suitable than flat frequency load shedding.
- With expected Mumbai Demand touching to 5000 MW and Generation Capacity of 2277 MW, existing islanding scheme will not work. The islanding scheme needs to be reviewed for possible load/generation balance and accordingly islands needs to be formed by separating other network. Initially, if possible both TPCL and R-Infra can be islanded together but independent islands would be required to be formed so that they survive on their own available load generation balance.
- Situational awareness at control centers can be enhanced through availability of synchrophasor data. Locations from where such data needs to be made available can be worked out jointly by the utilities in Mumbai. In fact when the TPCL operator attempted closure of the 220 kV Salsette bus coupler, immediately after tripping of the first 220 kV Trombay-Salsette circuit, one of the 220 kV buses at Salsette (connected to Trombay) underwent through three states viz. connected to rest of the grid initially, part of Dahanu island for a few seconds and then a blackout. It would be extremely difficult for the operator to visualize this change in states in the absence of synchrophasor data. With the rise in fault level, more and more 220 kV buses might need to be split in Mumbai system and availability of synchrophasor data would facilitate quick restoration of supplies through the bus couplers. To summarize, the committee recommends that option of installing PMU as a pilot project needs to be explored for this purpose.

6.2. Recommendations on Mumbai Network for Different Time Frames

6.2.1. Immediate Measures Based on Analysis of Existing Network

In general, the committee has observed that, existing Mumbai network is quite fragile. This can be observed from the fact that for Scenario-2 and Scenario-4 base cases without any contingency, multiple lines in the network are overloaded. This indicates need of network augmentation. Below are few important observations from the study of existing network,

- In almost all the studies, it is observed that, Aarey-Borivali 220 kV lines are carrying more than 200 MW per circuit, leaving little margin for further loading. Increased loading beyond 250 MW is presently controlled by load trimming scheme at R-Infra. It is suggested that, to cater peak demand in summer season, some of the Aarey load may be shifted to TPCL substations. Further feasibility studies needs to be carried out by the respective utilities for this alternative.
- Borivali-Borivali 220 kV line plays an important role in almost all events, and carrying substantial amount of power (generally in tune of 400 MW and above). Although, the current carrying capacity of the line is very high, the same is not true for associated in-feed lines including substation. It is recommended that these in-feed lines and substation equipments should be upgraded by MSETCL to handle higher loading.
- Considering the load growth, till network is augmented possibility of partial load shedding cannot be ruled out even during normal conditions. Also during contingencies, existing load trimming schemes would be required to be enhanced/modified/added to avoid tripping of healthy lines on overload.
- In view of LILO arrangement being carried out on 220 kV Borivali-Aarey Line at R-infra, shifting of R-infra's load to TPCL needs to be reviewed by the utilities.

6.2.2. Recommendations Based on Analysis of Augmented Network for the year 2012-13

- It is found from various studies conducted on existing and augmented (for the year 2012-13) network that, from transmission system point of view the network will be able to handle 'N-1' and 'N-1-1' (or N-2) contingencies after augmentation with load for around 4149 MW for completely connected augmented network with marginal overloads at few locations. By and large the augmented network will improve the security except that faults levels may go high at some buses (substations). This will require up-grading of substation equipments. This also may lead to splitting of buses and consequently reduce the security level. The committee recommends separate studies to be carried out for the bus splitting conditions.
- In absence of new generation availability in Mumbai regions, the additional load is supplied mainly through Kalwa, Boisar, and Borivali points. It should be noted that the

increasing interconnection at 220 kV also increases fault level (e.g., Kalwa substation). It is recommended that possibility of bus-split should be explored by the respective utilities at all such substations. In order to further contain the fault level and conserve ROW (which is a very serious problem in Mumbai region), future upgrades can consider 400 kV substations.

- The STU needs to co-ordinate studies of bus splitting as it is a planning related activity for the future.
- Currently, 110 kV Saki (TPCL) is being upgraded to 220 kV, and 220 kV Saki (R-Infra) is being commissioned. In view of better reliability, the committee recommends utilities to carry out feasibility studies for interconnecting Saki TPCL and Saki (R-Infra) substations.
- The generation outages are the most severe. Any outage of generation in Mumbai region does not converge the simulation until some generation is added locally (say at Kalwa). This indicates additional generation requirement in coming years in Mumbai system. If not physically located generation, extra power must be brought to the Mumbai network by any means to cater the load growth.

6.2.3. Analysis of Augmented Network for the year beyond 2012-13

- The Mumbai certainly requires augmentation in generation, either explicit or implicit. 400 kV network connectivity and HVDC will fill the gap of implicit generation addition. It is important that the two upgrades to the transmission network viz. 400 kV Vikhroli (TPCL) and 400 kV Ghodbunder (R-Infra) are taken up in right earnest immediately. Else there is a serious danger of all the transmission plans remaining only on paper. Fast execution of plans is therefore the key and all the agencies involved viz. STU, TPCL and R-Infra need to ensure this. If required, all possible help might be taken from the State Government, MERC and the CTU so that the transmission schemes are in place timely.
- Possibility of additional interconnection / LILO of existing 400 kV lines needs to be explored to establish additional capacity for importing power in Mumbai.

Non-completion of projects in given time frame would have serious implications on the security of Mumbai power system and possible congestion leading to load shedding. The committee hence recommends that implementation of all the MERC approved projects should be closely monitored by STU to streamline their completion within estimated time period.

Annexure – A

Ampacity of Conductors

(Source: CBIP Technical Report 77 of May 1991)

<u>ACSR Zebra</u> (54/3.18 mm AL + 7/3.18 mm Steel); Region: Northern; Maximum design temperature: 60, 65,67, and 75 degree Centrigrade, Conductor age: <u>up to one year</u>

Ambient temperature (Deg. C)	Ampacity (amperes) (60)	Ampacity (amperes) (65)	Ampacity (amperes) (67)	Ampacity (amperes) (75)
0.0	1090.3	1126.5	1140.5	1193.8
2.5	1067.8	1105.2	1119.5	1174.8
5.0	1044.9	1083.4	1098.4	1155.0
7.5	1021.4	1061.4	1076.8	1134.9
10.0	952.0	998.3	1013.1	1078.0
12.5	897.8	945.5	963.6	1030.5
15.0	839.4	891.2	910.5	982.4
17.5	784.9	840.7	861.6	963.1
20.0	766.2	823.4	844.8	947.8
22.5	708.9	771.3	794.4	903.6
25.0	658.3	724.1	749.1	864.1
27.5	604.0	701.2	728.0	826.6
30.0	541.7	647.5	877.2	783.2
32.5	503.8	596.1	628.7	742.6
35.0	495.0	588.9	622.0	737.3
37.5	378.6	495.6	535.1	667.4
40.0	352.2	477.6	518.6	654.3

<u>ACSR Zebra</u> (54/3.18 mm AL + 7/3.18 mm Steel); Region: Northern; Maximum design temperature: 60, 65,67, and 75 degree Centrigrade, Conductor age: <u>one to ten year</u>

Ambient temperature (Deg. C)	Ampacity (amperes) (60)	Ampacity (amperes) (65)	Ampacity (amperes) (67)	Ampacity (amperes) (75)
0.0	1147.8	1187.4	1202.8	1261.2
2.5	1124.8	1165.5	1181.1	1241.5
5.0	1101.2	1143.1	1159.4	1221.4
7.5	1076.9	1120.4	1137.2	1200.7
10.0	1003.8	1051.8	1070.0	1138.9
12.5	948.8	998.5	1018.2	1091.3
15.0	885.4	941.4	962.5	1040.9
17.5	828.1	888.5	911.1	1018.2
20.0	809.0	870.8	894.0	1002.7
22.5	748.7	616.2	841.2	956.4
25.0	693.8	768.7	793.8	915.2
27.5	639.2	740.5	769.0	876.0
30.0	571.1	694.1	716.2	830.5
32.5	530.6	630.1	685.2	788.3
35.0	522.4	623.2	658.8	783.0
37.5	397.2	524.7	567.2	709.5
40.0	371.9	506.2	550.3	696.2

<u>ACSR Zebra</u> (54/3.18 mm AL + 7/3.18 mm Steel); Region: Northern; ; Maximum design temperature: 60, 65,67, and 75 degree Centrigrade; Conductor age: <u>Beyond ten year</u>

Ambient temperature (Deg. C)	Ampacity (amperes) (60)	Ampacity (amperes) (65)	Ampacity (amperes) (67)	Ampacity (amperes) (75)
0.0	1168.3	1207.0	1222.6	1282.8
2.5	1143.1	1184.9	1201.0	1263.0
5.0	1119.3	1162.3	1179.1	1242.8
7.5	1094.8	1139.4	1156.7	1221.9
10.0	1022.3	1071.4	1090.1	1160.6
12.5	965.7	1018.4	1038.5	1113.3
15.0	904.6	961.7	983.2	1063.3
17.5	847.7	909.1	932.2	1040.4
20.0	828.1	891.0	914.6	1024.5
22.5	768.3	836.7	862.2	978.4
25.0	713.5	787.5	814.9	937.3
27.5	659.5	760.9	790.7	898.2
30.0	594.2	704.9	737.3	853.0
32.5	551.9	651.3	686.6	810.8
35.0	542.1	643.2	679.9	804.6
37.5	420.5	546.6	589.0	732.0
40.0	394.3	527.1	571.1	717.9

ACSR Moose (54/3.53 mm AL + 7/3.53 mm Steel); Region: Northern; Maximum design temperature: 60, 65,67, and 75 degree Centrigrade, Conductor age: up to one year

Ambient temperature (Deg. C)	Ampacity (amperes) (60)	Ampacity (amperes) (65)	Ampacity (amperes) (67)	Ampacity (amperes) (75)
0.0	1259.0	1301.8	1316.0	1379.8
2.5	1234.0	1277.2	1293.6	1357.6
5.0	1207.5	1252.1	1269.4	1335.1
7.5	1180.3	1226.7	1244.6	1311.8
10.0	1098.3	1149.7	1169.3	1242.3
12.5	1034.5	1089.9	1110.9	1188.7
15.0	965.5	1025.9	1048.3	1132.0
17.5	901.2	968.3	990.6	1080.2
20.0	880.0	948.7	971.6	1083.4
22.5	812.3	885.2	912.2	1011.0
25.0	750.3	829.7	858.9	964.4
27.5	689.2	775.9	807.4	920.3
30.0	614.6	711.7	746.4	868.8
32.5	541.1	650.4	688.5	821.1
35.0	534.5	645.0	683.6	817.1
37.5	384.9	530.1	577.3	732.6
40.0	358.4	511.7	580.5	719.5

ACSR Moose (54/3.53 mm AL + 7/3.53 mm Steel); Region: Northern; Maximum design temperature: 60, 65,67, and 75 degree Centrigrade, Conductor age: one to ten year

Ambient temperature (Deg. C)	Ampacity (amperes) (60)	Ampacity (amperes) (65)	Ampacity (amperes) (67)	Ampacity (amperes) (75)
0.0	1328.6	1374.5	1392.2	1460.3
2.5	1302.0	1349.3	1367.5	1437.6
5.0	1274.7	1323.4	1342.4	1414.4
7.5	1246.8	1297.3	1316.8	1390.5
10.0	1160.3	1216.2	1237.5	1317.5
12.5	1093.2	1153.4	1176.3	1261.5
15.0	1020.7	1086.1	1110.6	1202.1
17.5	953.1	1023.7	1050.1	1148.0
20.0	931.4	1003.7	1030.7	1130.9
22.5	860.3	939.2	968.5	1076.1
25.0	795.3	881.1	912.7	1027.5
27.5	731.2	824.5	858.9	961.4
30.0	652.9	757.5	795.0	927.6
32.5	575.7	693.3	734.4	677.8
35.0	569.4	688.1	729.7	874.0
37.5	412.3	567.5	618.1	785.4
40.0	384.9	548.4	600.8	771.9

ACSR Moose (54/3.53 mm AL + 7/3.53 mm Steel); Region: Northern; Maximum design temperature: 60, 65,67, and 75 degree Centrigrade, Conductor age: Beyond ten year

Ambient temperature (Deg. C)	Ampacity (amperes) (60)	Ampacity (amperes) (65)	Ampacity (amperes) (67)	Ampacity (amperes) (75)
0.0	1350.7	1397.9	1418.1	1488.2
2.5	1323.9	1372.4	1391.1	1483.3
5.0	1296.4	1346.4	1365.8	1439.9
7.5	1268.1	1319.9	1340.0	1415.6
10.0	1182.4	1239.5	1261.4	1343.5
12.5	1115.7	1177.2	1200.6	1287.8
15.0	1043.8	1110.4	1135.4	1228.9
17.5	976.7	1048.5	1075.4	1175.2
20.0	954.4	1027.9	1055.4	1157.5
22.5	883.9	963.9	993.7	1103.1
25.0	819.3	906.1	938.1	1054.7
27.5	755.7	850.1	884.6	1008.8
30.0	678.5	783.5	821.2	955.3
32.5	602.5	719.6	761.2	905.8
35.0	594.3	713.6	754.9	900.7
37.5	443.2	595.4	645.8	913.5
40.0	414.6	575.0	627.1	798.9

<u>ACSR Bersimis</u> (42/4.57 mm AL + 7/2.54 mm Steel); Region: Northern; Maximum design temperature: 60, 65,67, and 75 degree Centrigrade, Conductor age: <u>up to one year</u>

Ambient temperature (Deg. C)	Ampacity (amperes) (60)	Ampacity (amperes) (65)	Ampacity (amperes) (67)	Ampacity (amperes) (75)
0.0	1498.6	1548.7	1568.0	1641.7
2.5	1467.9	1519.5	1539.3	1615.4
5.0	1436.5	1489.7	1510.4	1588.6
7.5	1404.2	1459.5	1480.8	1561.0
10.0	1304.6	1365.9	1389.3	1476.5
12.5	1227.1	1293.4	1318.6	1411.7
15.0	1143.4	1215.6	1242.6	1342.8
17.5	1065.3	1143.5	1172.7	1280.2
20.0	1040.6	1120.6	1150.5	1260.6
22.5	958.4	1046.1	1078.5	1197.1
25.0	883.2	978.8	1014.0	1140.9
27.3	809.0	913.7	951.7	1087.6
30.0	718.0	835.7	877.6	1025.3
32.5	627.9	761.1	807.4	967.7
35.0	622.1	756.4	803.1	964.2
37.5	434.8	614.6	672.3	860.9
40.0	404.2	593.9	653.5	846.3

<u>ACSR Bersimis</u> (42/4.57 mm AL + 7/2.54 mm Steel); Region: Northern; Maximum design temperature: 60, 65,67, and 75 degree Centrigrade, Conductor age: <u>one to ten year</u>

Ambient temperature (Deg. C)	Ampacity (amperes) (60)	Ampacity (amperes) (65)	Ampacity (amperes) (67)	Ampacity (amperes) (75)
0.0	1583.1	1638.0	1659.2	1740.6
2.5	1551.5	1608.0	1629.7	1713.6
5.0	1519.0	1577.2	1599.9	1686.0
7.5	1485.8	1546.1	1569.4	1657.6
10.0	1380.8	1447.6	1473.2	1569.0
12.5	1299.5	1371.6	1399.0	1501.2
15.0	1211.4	1289.9	1319.4	1429.2
17.5	1129.5	1214.3	1246.1	1363.7
20.0	1104.1	1190.9	1223.4	1343.7
22.5	1017.8	1112.8	1148.1	1277.4
25.0	938.9	1042.4	1060.5	1218.7
27.5	861.2	974.3	1015.5	1163.1
30.0	765.8	892.6	937.9	1098.1
32.5	671.5	814.6	864.5	1037.0
35.0	665.8	810.0	860.3	1034.5
37.5	470.1	661.7	723.4	926.5
40.0	438.3	640.7	703.9	911.4

<u>ACSR Bersimis</u> (42/4.57 mm AL + 7/2.54 mm Steel); Region: Northern; Maximum design temperature: 60, 65,67, and 75 degree Centrigrade, Conductor age: <u>Beyond ten year</u>

Ambient temperature (Deg. C)	Ampacity (amperes) (60)	Ampacity (amperes) (65)	Ampacity (amperes) (67)	Ampacity (amperes) (75)
0.0	1610.2	1666.7	1688.5	1772.3
2.5	1578.3	1636.4	1658.8	1745.1
5.0	1545.6	1605.4	1628.7	1717.3
7.5	1512.0	1573.9	1597.9	1688.8
10.0	1407.9	1476.3	1502.5	1600.8
12.5	1327.1	1400.8	1428.9	1533.5
15.0	1239.8	1319.8	1349.9	1462.1
17.5	1158.5	1244.8	1277.2	1397.2
20.0	1132.4	1220.7	1253.8	1376.5
22.5	1046.9	1143.2	1179.0	1310.7
25.0	968.7	1073.3	1111.9	1252.2
27.5	891.6	1005.6	1047.2	1196.9
30.0	797.6	924.8	970.4	1132.3
32.5	705.0	847.6	897.7	1072.4
35.0	696.9	841.0	891.6	1067.5
37.5	509.5	696.6	757.9	961.3
40.0	476.3	693.3	736.7	944.8

Annexure – B

Contingency Studies and Results of Existing Mumbai Network

List of Contingency

Contingency Number	Scenario-1	Scenario-3
	Base Case	
1	Trombay-Salsette 220 kV ckt 1out	
2	Trombay-Salsette 220 kV ckt 1 and 2 out	
3	Kalwa-Salsette 220 kV ckt 3 out	
4	Kalwa-salsette 220 kV ckt 3 and 4 out	
5	Dahanu – Ghodbundar 220 kV ckt 1out	
6	Dahanu – Ghodbundar 220 kV ckt 1 and 2 out	
7	Borivali-Salsette 220 kV ckt 1out	
8	Borivali-Salsette 220 kV ckt 1&2 out	
9	Borivali-Aarey 220 kV ckt 1 out	
10	Boisar-Versova 220 kV ckt out	
11	Boisar-Dahanu 220 kV ckt out	

12	Dahanu-Varsova 220 kV ckt out		
13	Borivali-Kalwa 220 kV ckt out		
14	Dahanu unit 1 out		
15	Trombay unit 5 out		
Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Base Case			

The total power generation of system is 16,107 MW, including 350 MW of wind generation. Total system demand is 15,453 MW with losses of 654 MW. It can be observed that in case of Scenario-1, when all components are in service and Senario-3, when Salsette Bus-Coupler is out, all line flows are within limit except, Aarey-Borivali 220 kV line carrying approximately 218 MW on each circuit.

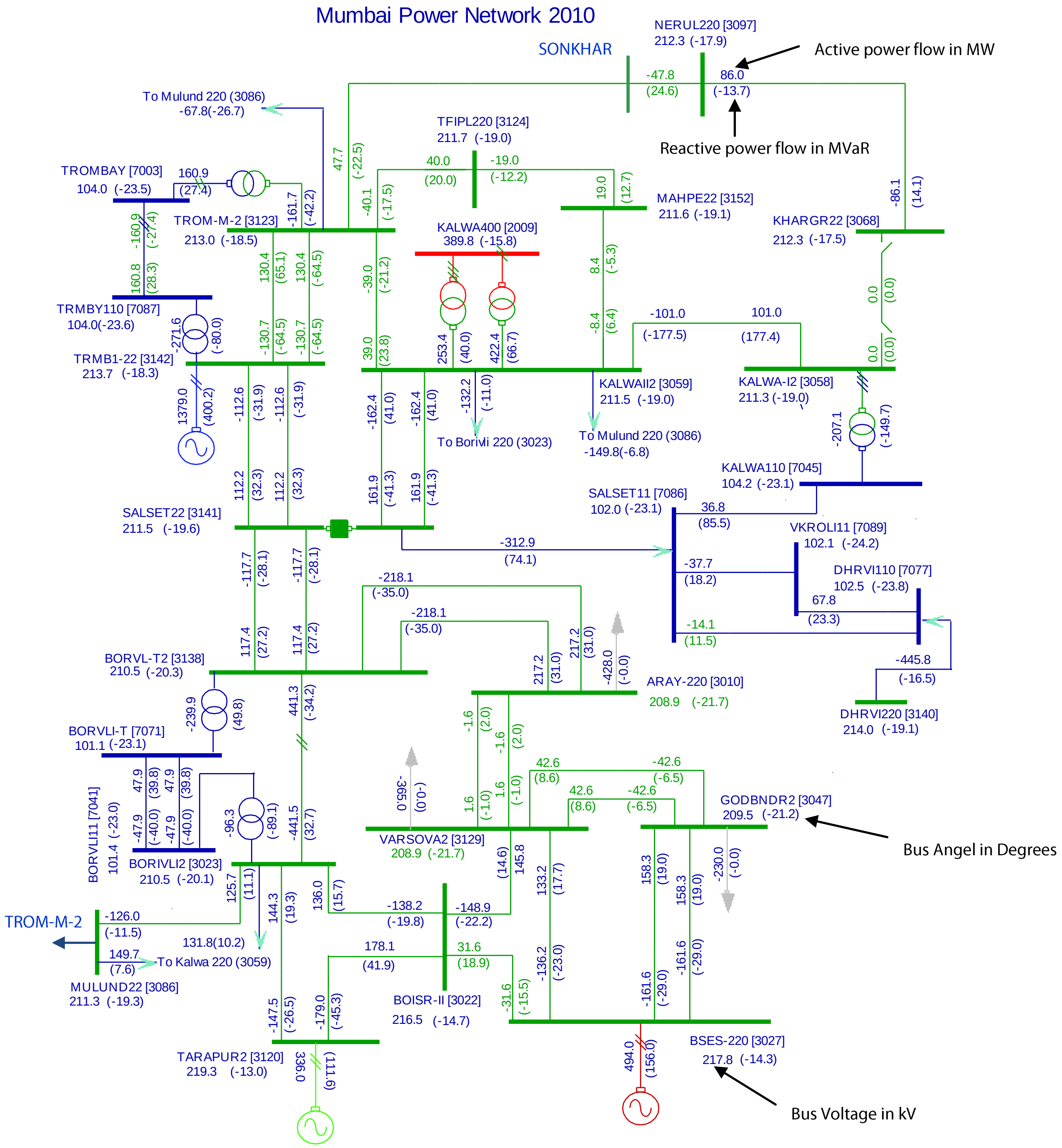

Fig. B1. Base Case of Scenario-1

Note:

- All lines flow values are in MW
- All values in "()" indicates reactive power flow in MVaR or bus angle in degrees
- "-" (minus) sign of power flow indicates "From End"

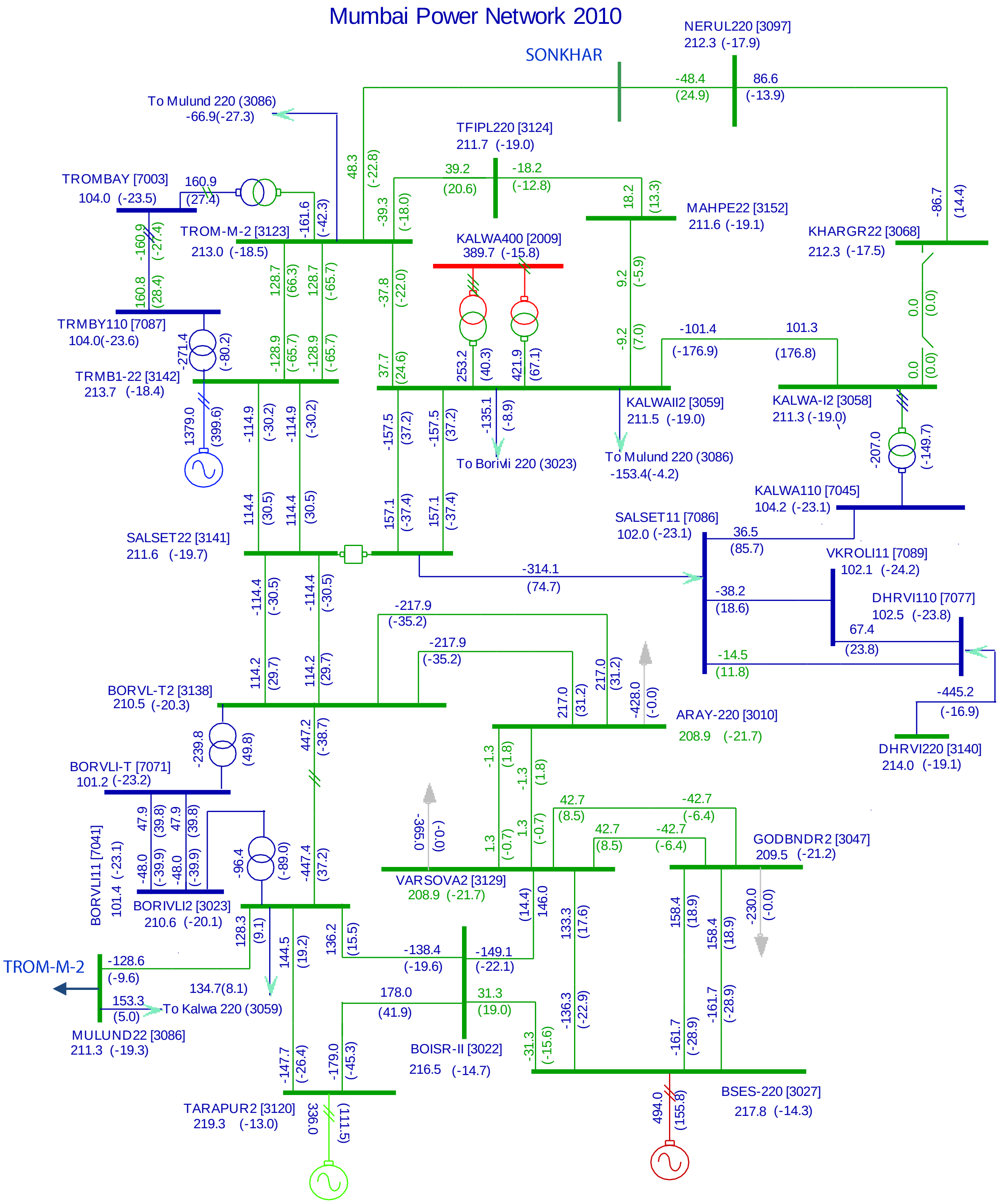

Fig. B2. Base Case of Scenario-3

<table>
<tr><td>Borivali-Borivali 220 kV In Service</td><td>Salsette Bus Coupler In Service</td><td>Borivali-Borivali 220 kV In Service</td><td>Salsette Bus Coupler not in Service</td></tr>
<tr><td colspan="2">Scenario-1</td><td colspan="2">Scenario-3</td></tr>
<tr><td colspan="4">Trombay – Salsette-1 Out</td></tr>
</table>

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Outage of single circuit (ckt) of Trombay – Salsette can be successfully handled by the system.
- Aarey – Varsova corridor is floating carring very small amount of power.
- Borivali – Aarey corridor (double circuit) is near to its loading limit.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- System is able to handel outage of Trombay – Salsette single ckt line.
- Although flow over all the lines are in control, loading of Borivali-Borivali line and Borivali-Kalwa lines increase by little amount as compared to the previous case. This indicates that with contingency, Kalwa will have to handle higher amount of power.

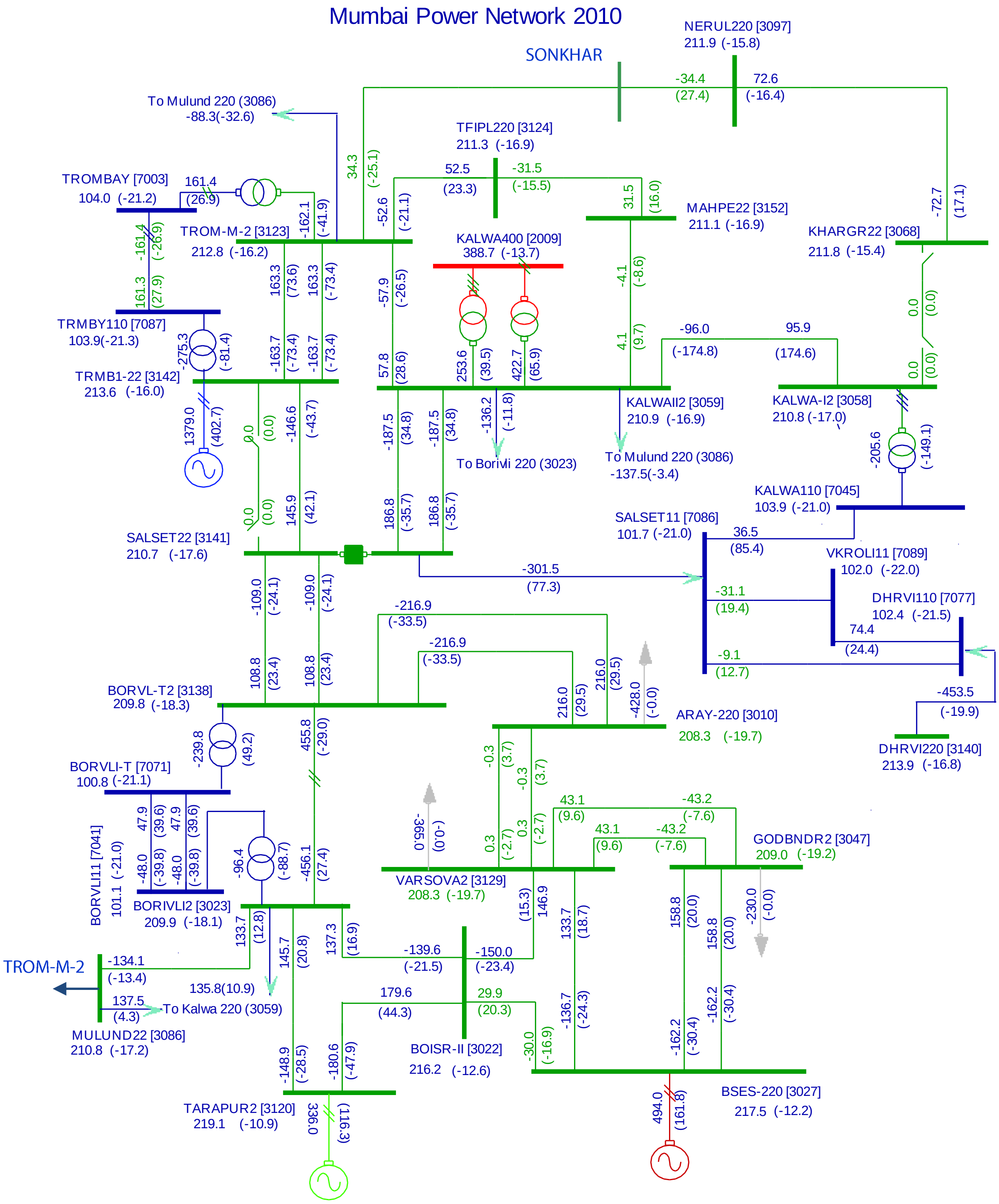

Fig. B3. Base Case of Scenario-1 with Trombay-Salsette 1 ckt out

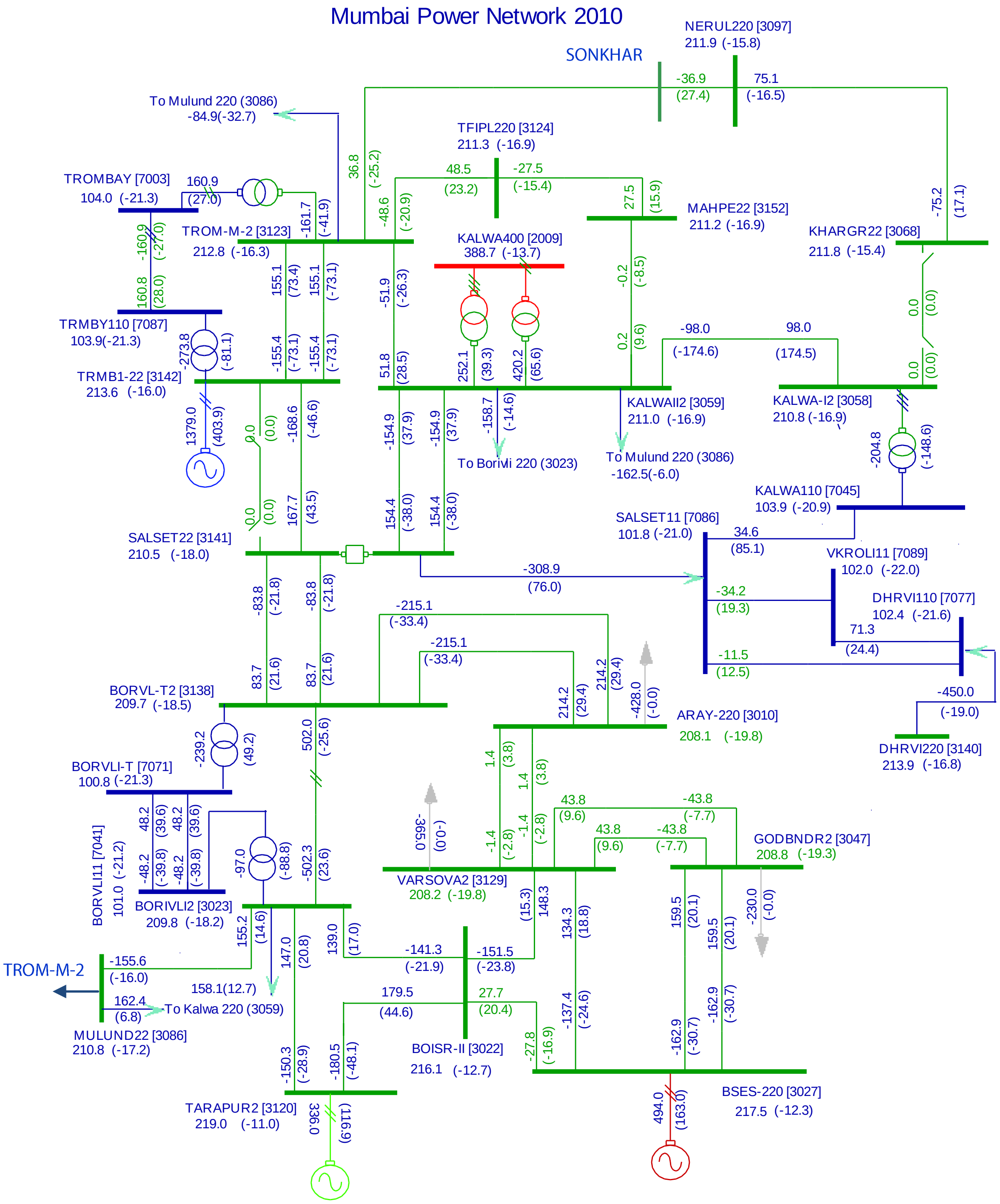

Fig. B4. Base Case of Scenario-3 with Trombay-Salsette 1 ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Trombay – Salsette-1&2 Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Flow over Kalwa-Salsette line increases from 162 MW (base case) to 234 MW with both the Trombay-Salsette lines out.
- Flow over Trombay-Trombay line increases from 131 MW (base case) to 225 MW.
- Aarey – Varsova corridor is flooting carring very small amount of power.
- Borivali – Aarey corridor (double circuit) is near to its loading limit.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- Flow over Trombay-Trombay line increases from 129 MW (base case) to 228 MW.
- Borivali-Borivali line carries 656 MW (over loaded). Although Borivali-Borivali line may be able to carry that power safely, the equipment at either end should be upgraded to handle the same amount of power.
- Kalwa-Borivali carries power in the tune of 225 MW.

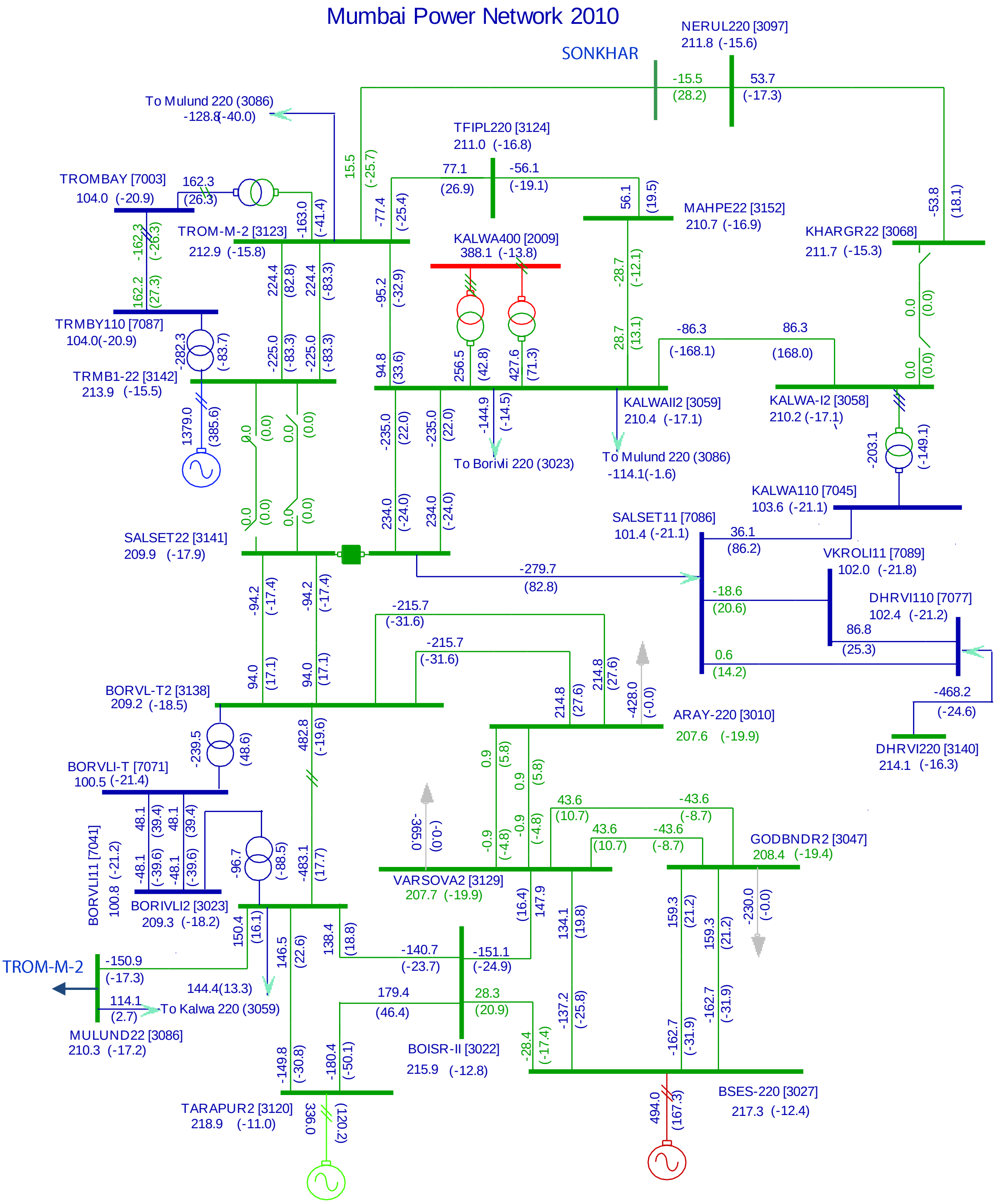

Fig. B5. Base Case of Scenario-1 with Trombay-Salsette 1&2 ckt out

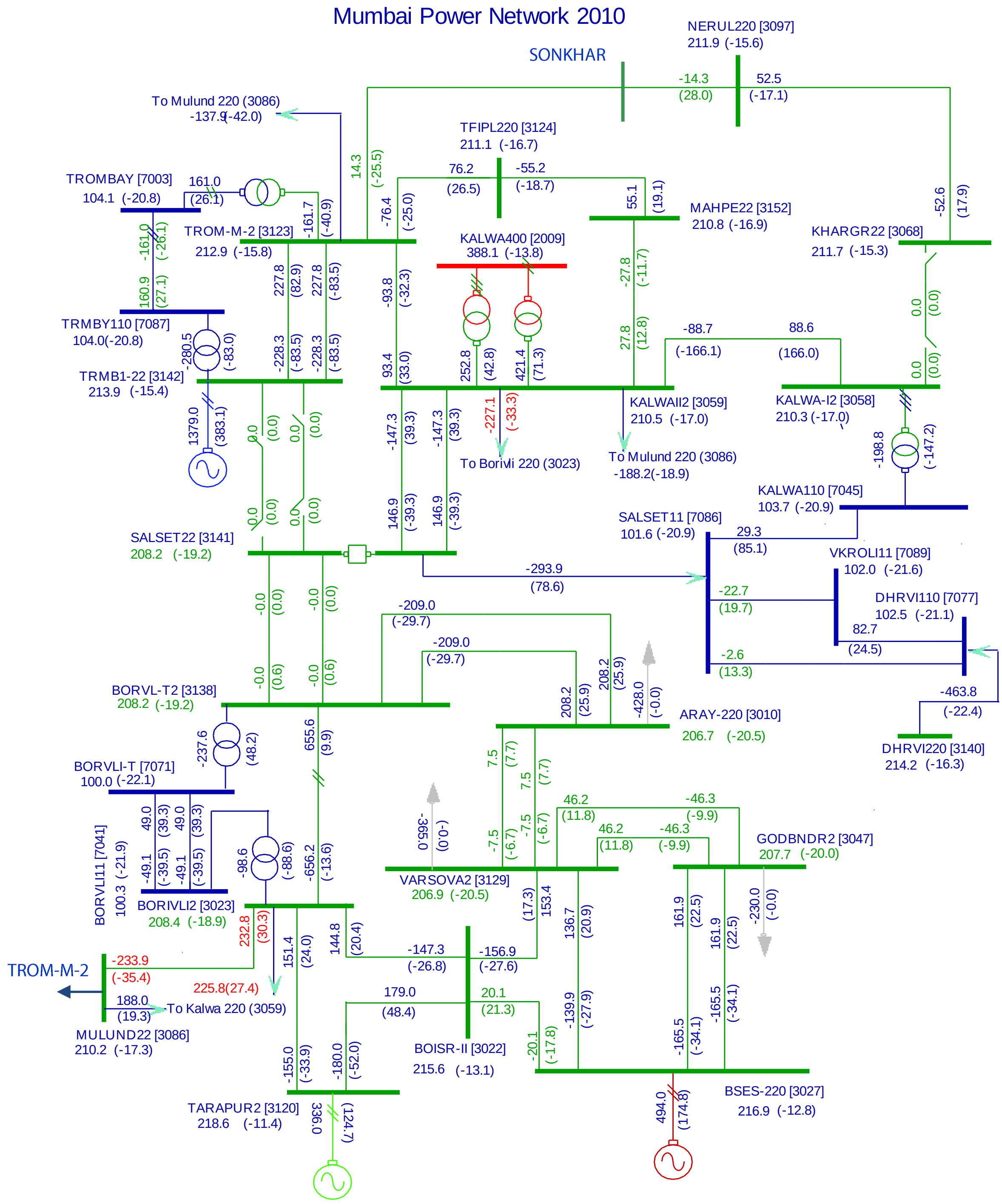

Fig. B6. Base Case of Scenario-3 with Trombay-Salsette 1&2 ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Kalwa – Salsette-3 Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Flow over Kalwa-Salsette line increases from 162 MW (base case) to 246 MW. Rest of the lines are loaded more or less same as the base case.
- Aarey – Varsova corridor is flooting carring very small amount of power.
- Borivali – Aarey corridor (double circuit) is near to its loading limit.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- Flow over Kalwa-Salsette line increases from 157 MW (base case) to 295 MW. Rest of the lines are loaded more or less same as the base case.
- Rest of the lines are loaded more or less same as the base case.

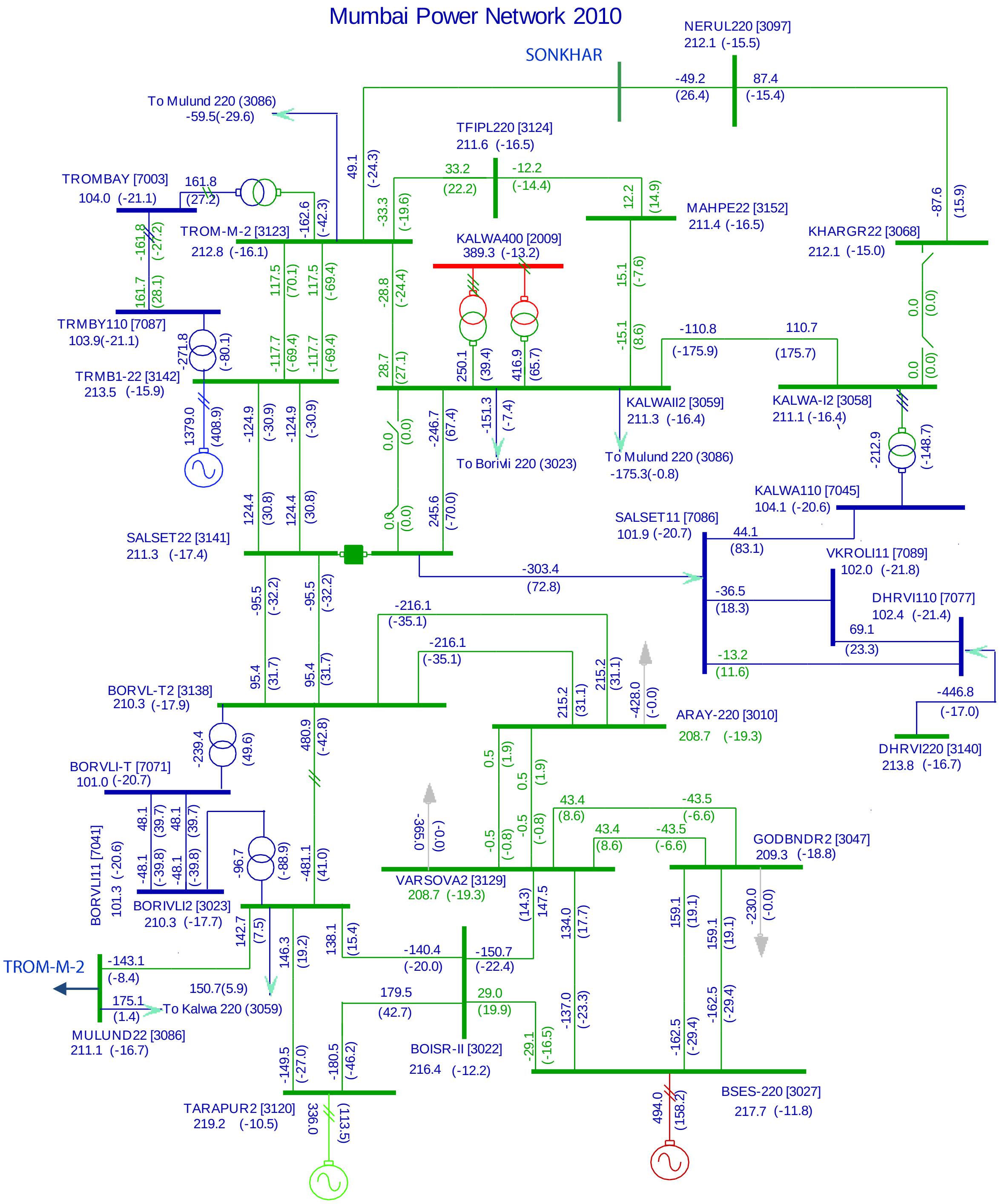

Fig. B7. Base Case of Scenario-1 with Kalwa-Salsette 3 ckt out

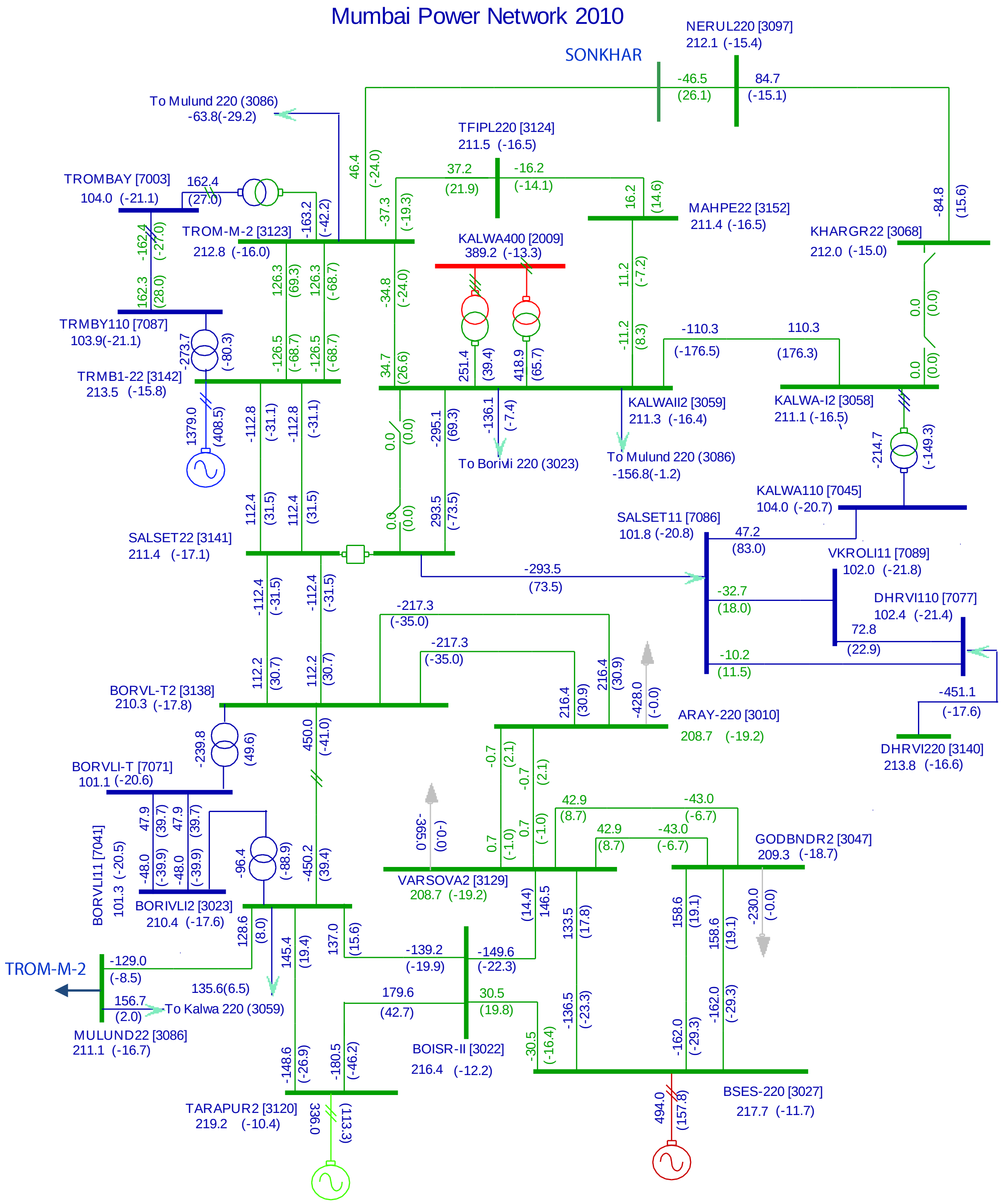

Fig. B8. Base Case of Scenario-3 with Kalwa-Salsette 3 ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Kalwa – Salsette-3&4 Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- With bus-coupler in service , Salsette ICT keeps feeding Vikhroli, Dharavi, and other radial load.
- Borivali-Borivali lines carry more than 600 MW.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- With Bus-couple out of service, Salsette ICTdoesn not get feed.
- Loading of Kalwa-Kalwa interconnector line increases from 101 MW (in base case) to 247 MW with the contingency.

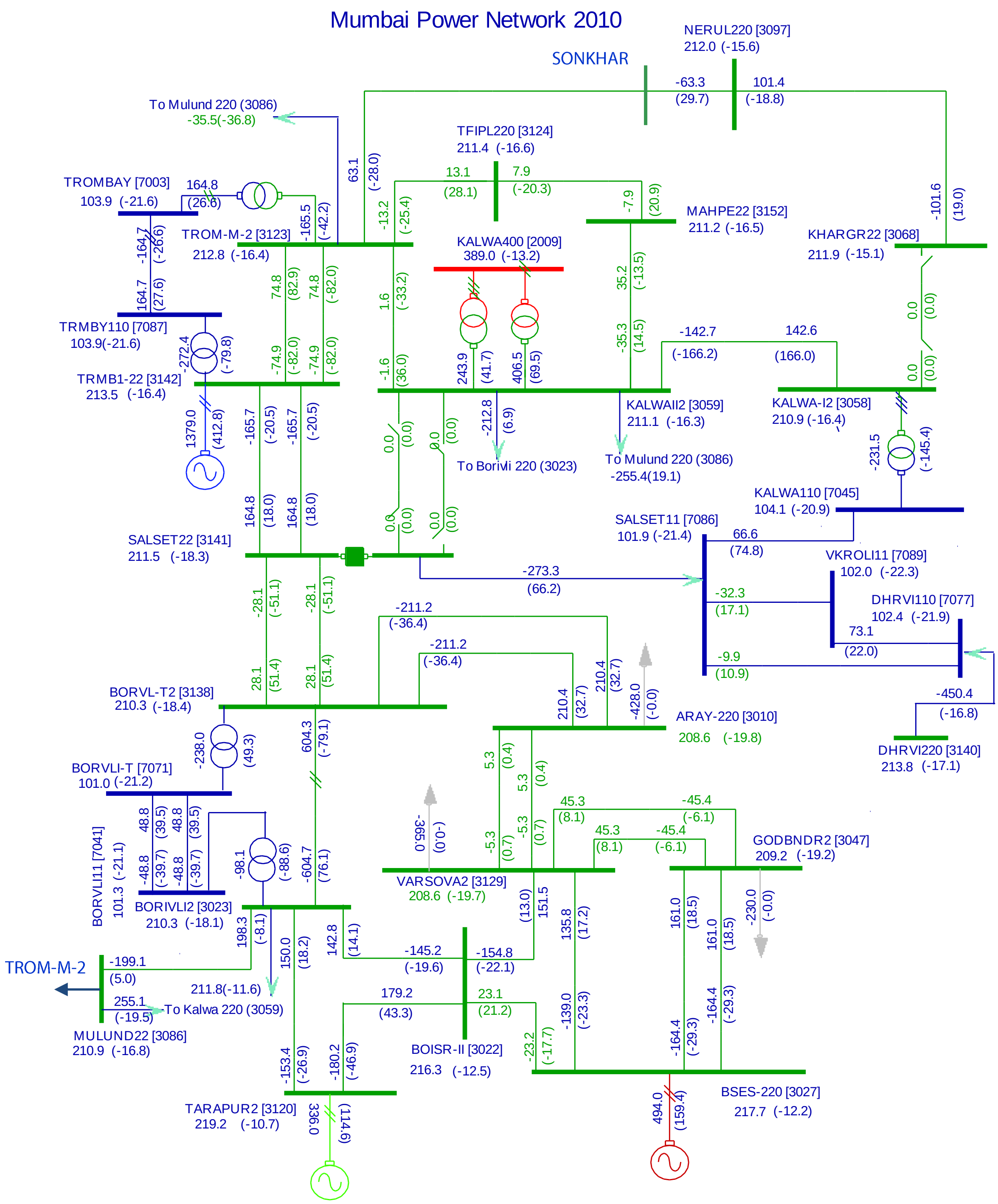

Fig. B9. Base Case of Scenario-1 with Kalwa-Salsette 3&4 ckt out

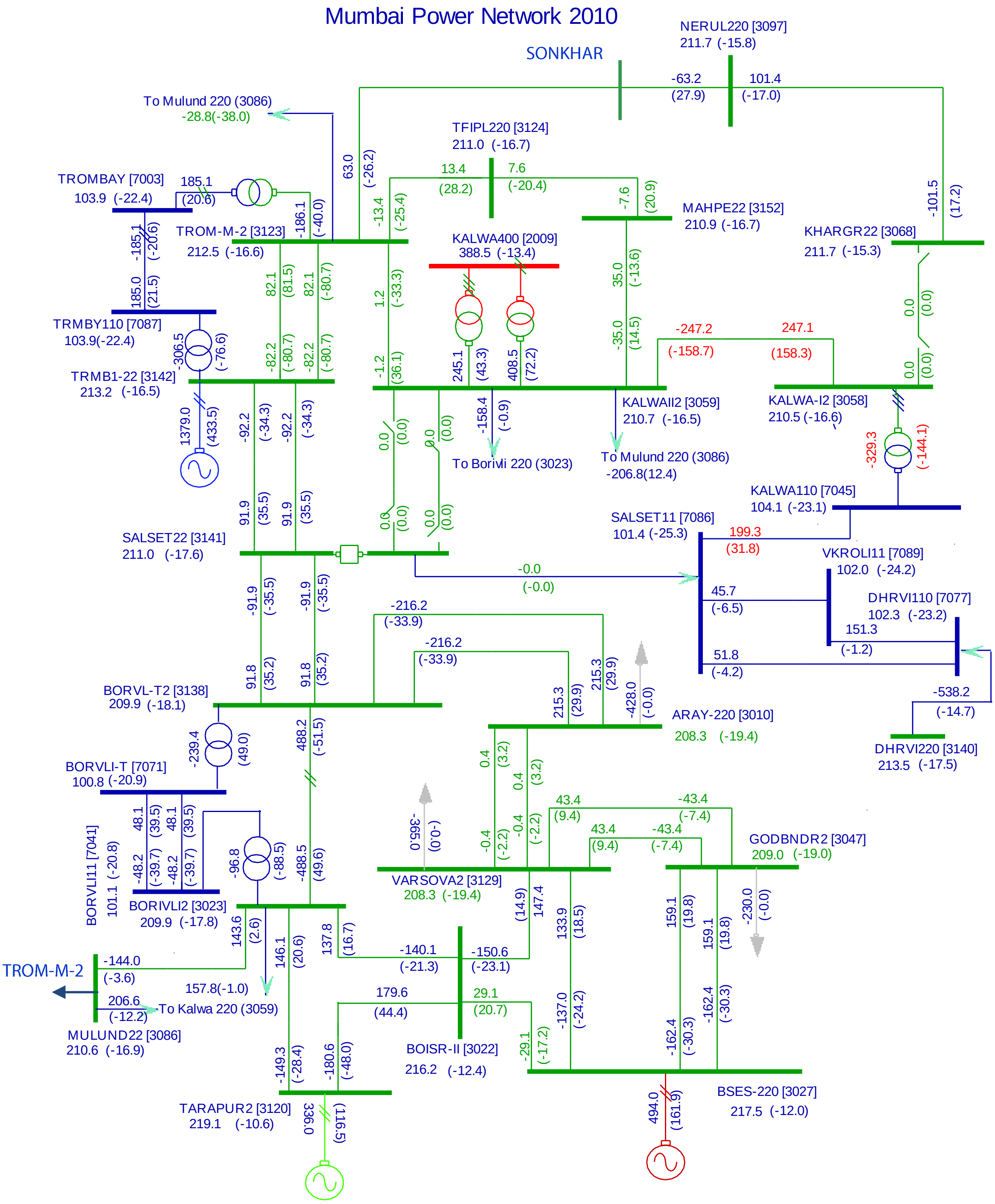

Fig. B10. Base Case of Scenario-3 with Kalwa-Salsette 3&4 ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Dahanu – Ghodbundar-1 Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Flow over 2nd circuit of Dahanu – Ghodbundar increases.
- Aarey-Varsova line, which was amost floating in earlier cases, now carries 39 MW of power to support Varsova load.
- Aareay-Borivali line hits the upper limit of 255 MW, carrying 256 MW each circuit. R-Infra's load trimming scheme will be activated at 255 MW loading condition.
- No major flow variations are observed in rest of the network.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- The situation is similar to that of above, however the flow over Borivali-Borivali line increase marginally.

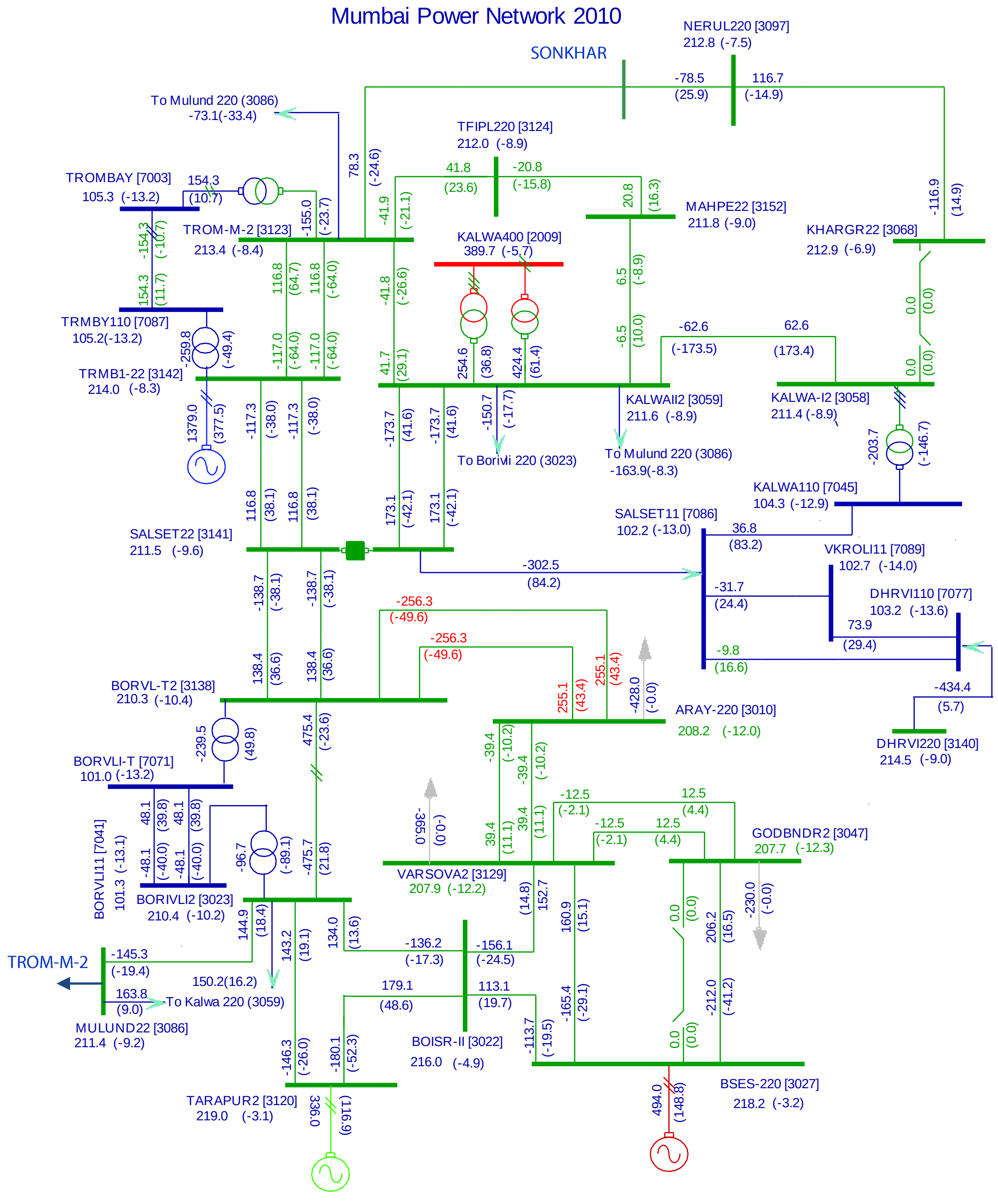

Fig. B11. Base Case of Scenario-1 with Dahanu-Ghodbundar 1 ckt out

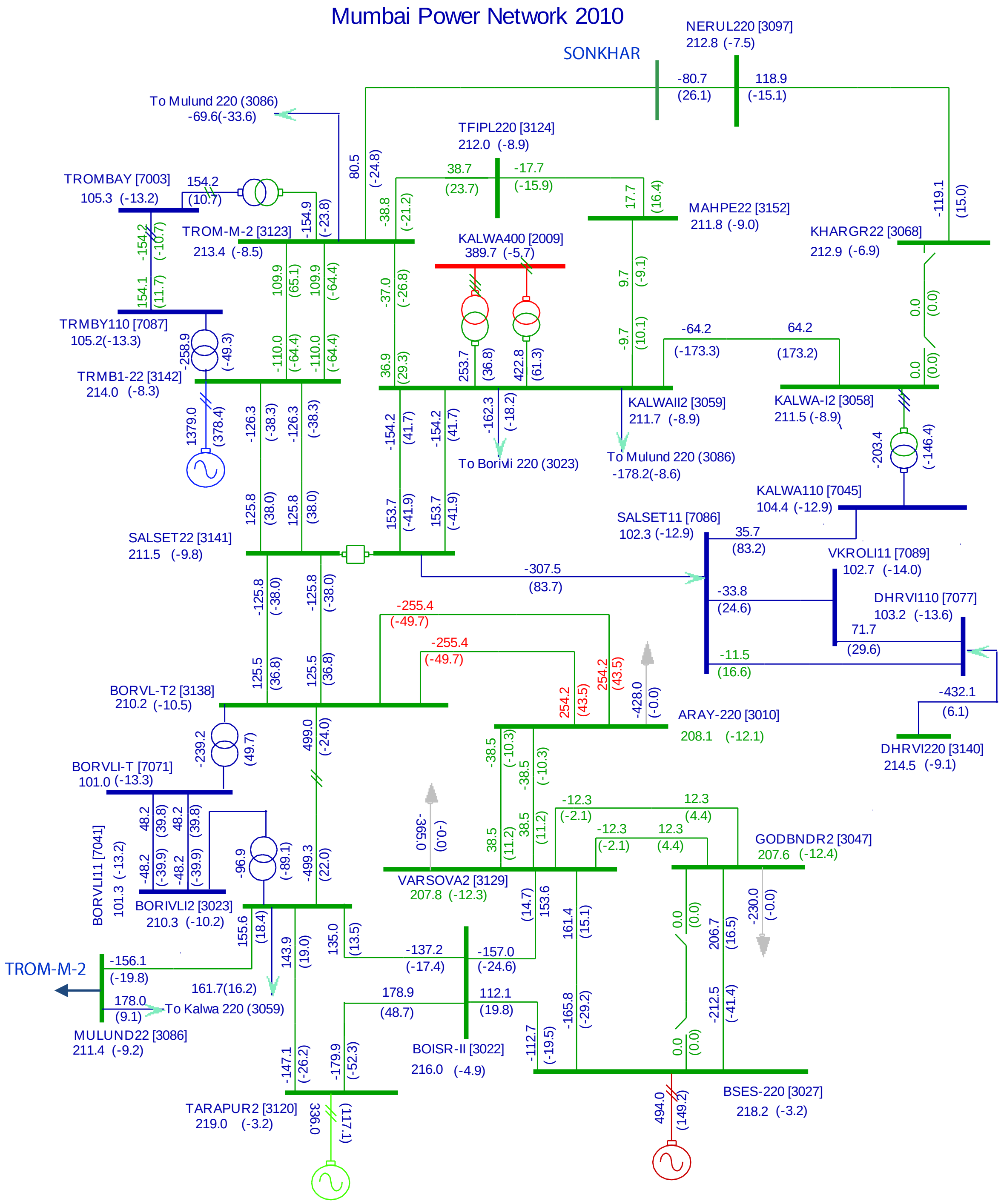

Fig. B12. Base Case of Scenario-3 with Dahanu-Ghodbundar 1 ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Dahanu – Ghodbundar-1&2 Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Flow over Dahanu-Boisar line increases from 32 MW (in base case) to 253 MW with the contingency.
- Flow over Dahanu-Varsova line increases from 136 MW (in base case) to 234 MW with the contingency.
- Flow over Godbundar-Varsova line increases from 43 MW (in base case) to 116 MW in reverse direction feeding Ghodbundar load.
- Aarey-Varsova line, which was amost floating in earlier cases, now carries 94 MW of power to support Varsova load.
- Aareay-Borivali line is over loaded carrying 312 MW.
- Borivali-Borivali line carrynig slightly less than 550 MW.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- The situation is similar to that of above, however the flow over Borivali-Borivali line increase up to 590 MW and flow of Kalwa-Borivali line increases from 135 MW (in base case) to 187 MW.

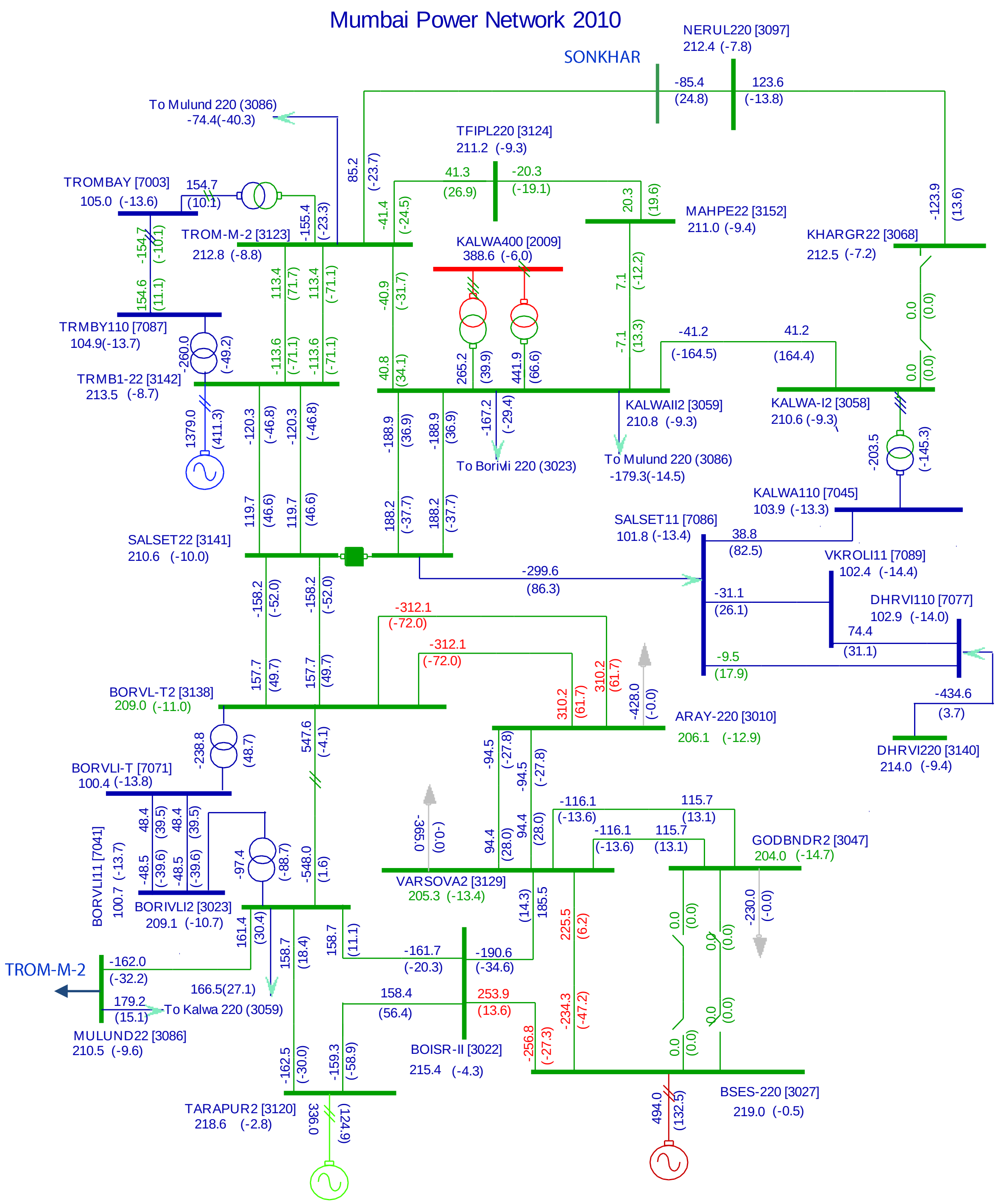

Fig. B13. Base Case of Scenario-1 with Dahanu-Ghodbundar 1&2 ckt out

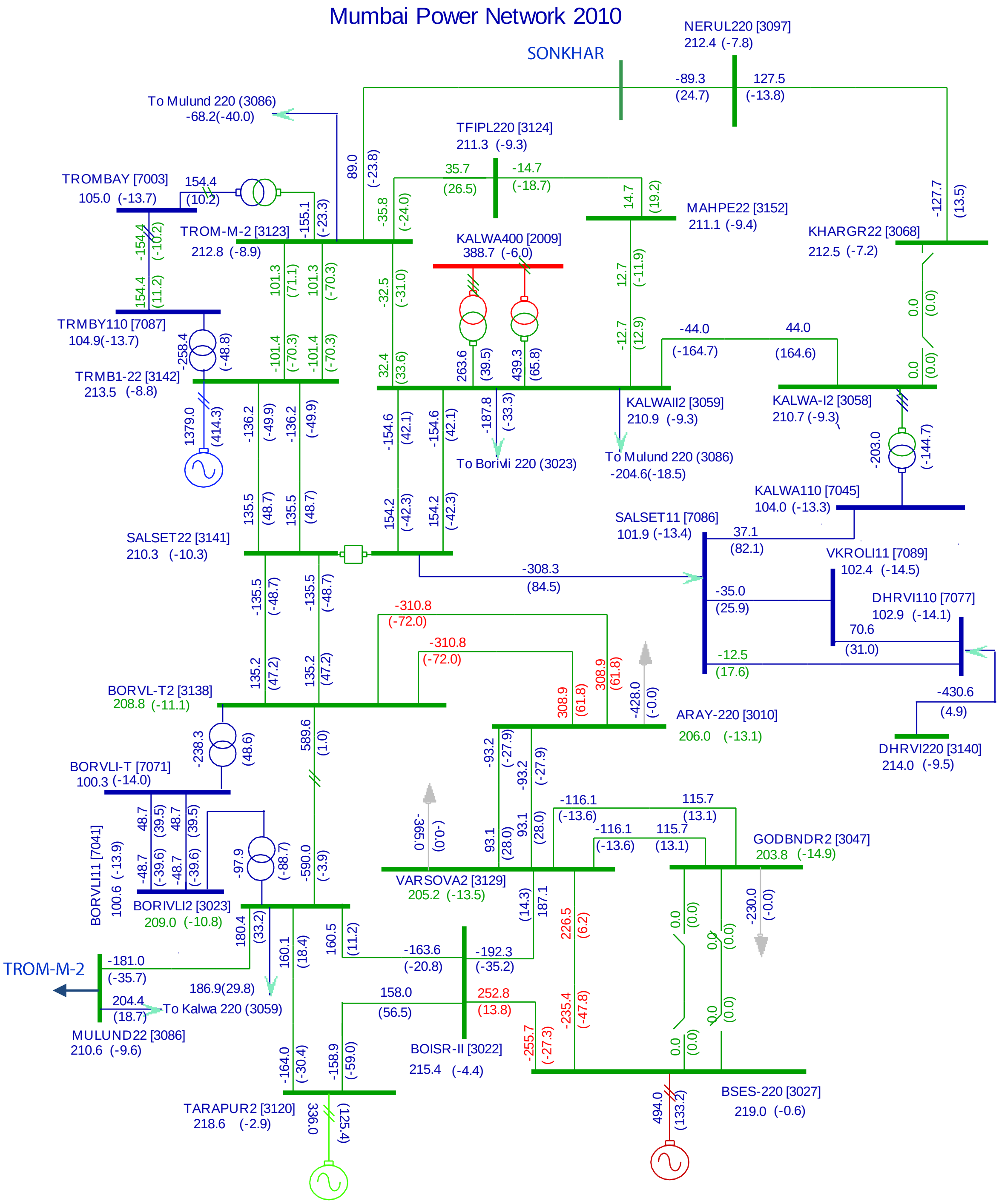

Fig. B14. Base Case of Scenario-3 with Dahanu-Ghodbundar 1&2 ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Borivali –Salsette-1 Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Flow on 2^{nd} ckt of Borivali-Salsette line increase up to 172 MW.
- Loading condition on rest of the network does not change substantially from the base case.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- Flow on 2^{nd} ckt of Borivali-Salsette line increase up to 172 MW.
- Loading condition on rest of the network does not change substantially from the base case.

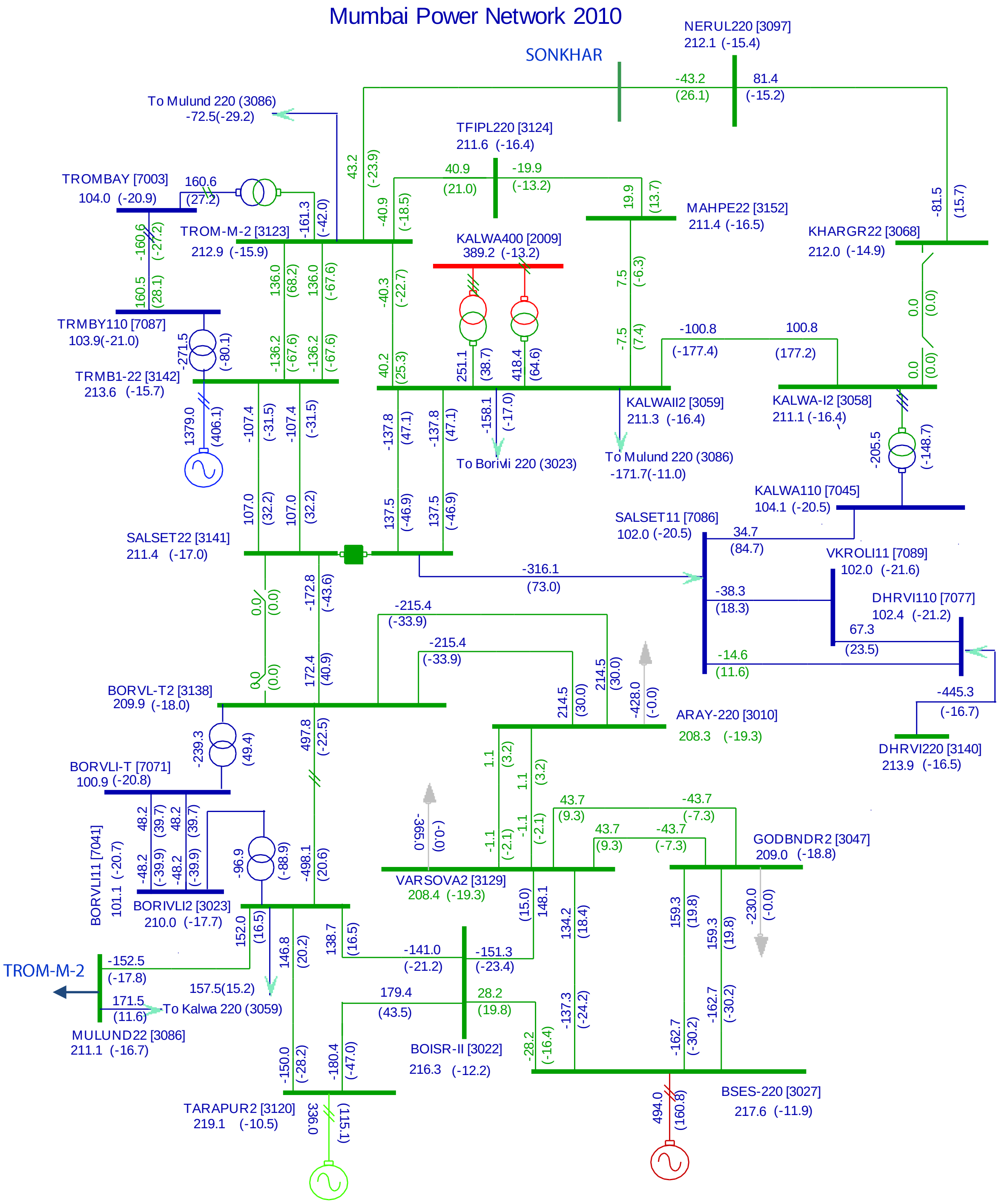

Fig. B15. Base Case of Scenario-1 with Borivali – Salsette 1 ckt out

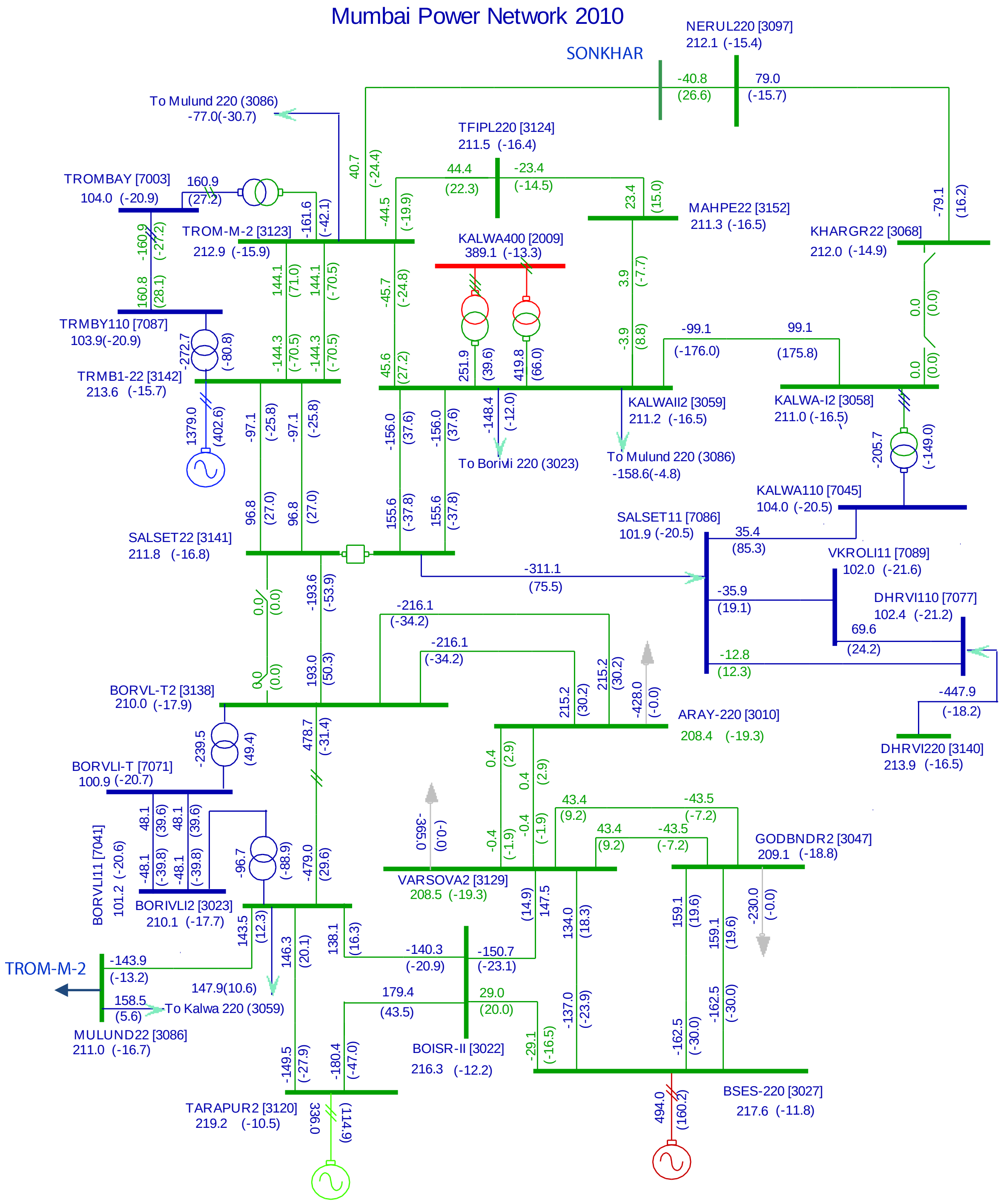

Fig. B16. Base Case of Scenario-3 with Borivali – Salsette 1 ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Borivali –Salsette-1&2 Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Borivali-Borivali lines get overloaded carrying 657 MW.
- Borivali – Mulund line carries 229 MW as compared to 126 MW in base case.
- Loading of Aarey-Borivali lines decreases marginally.
- Borivali – Kalwa line carries 231 MW as compared to 132 MW in base case.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- With Salsette B/C out of service, Trombay-Salsette and Salsette-Borivali corridor becomes radial, carrying no power.
- Borivali-Borivali line gets overloaded carrying 657 MW.
- Borivali – Mulund line carries 234 MW as compared to 128 MW in base case.
- Borivali – Kalwa line carries 226 MW as compared to 135 MW in base case.

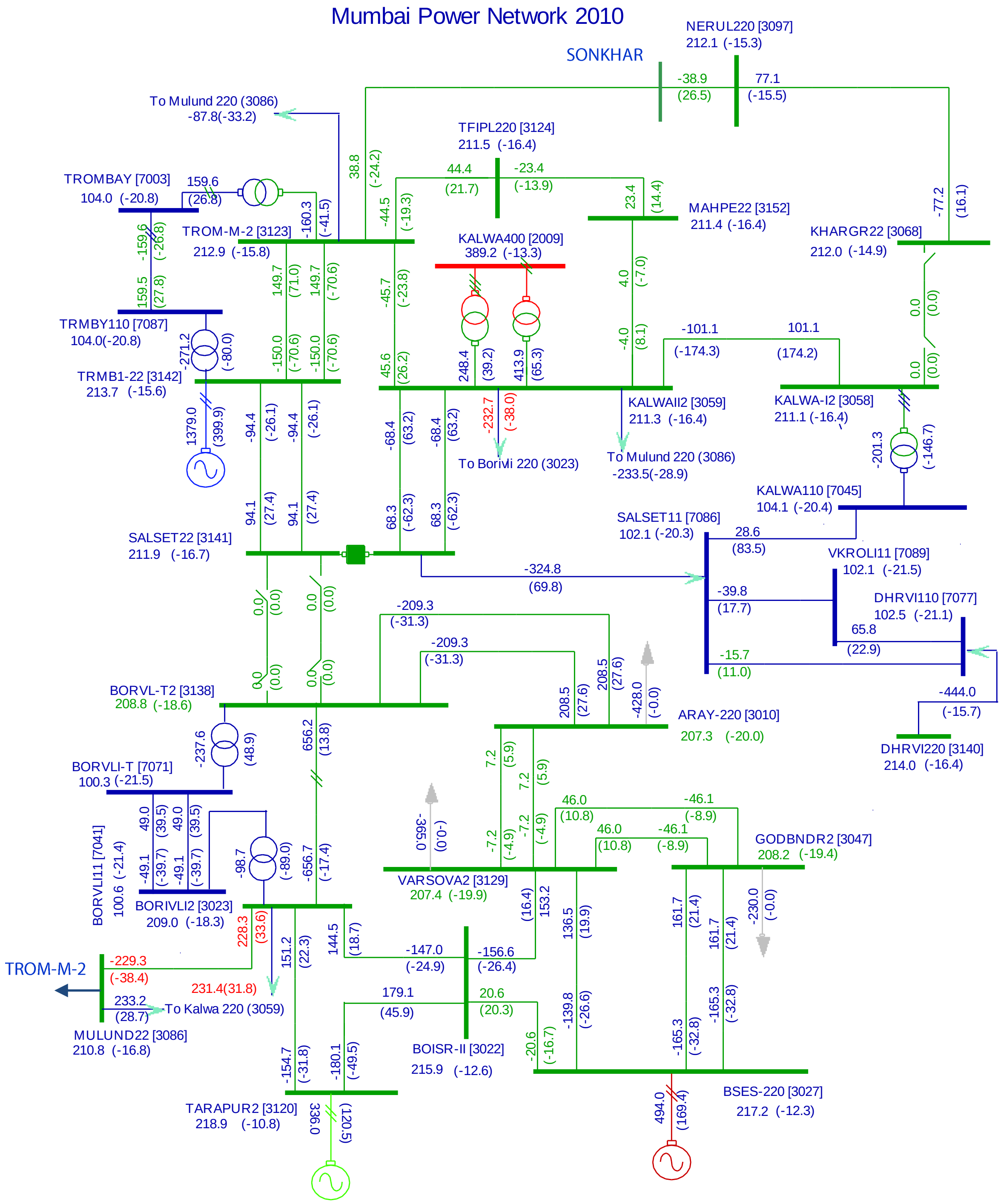

Fig. B17. Base Case of Scenario-1 with Borivali – Salsette 1&2 ckt out

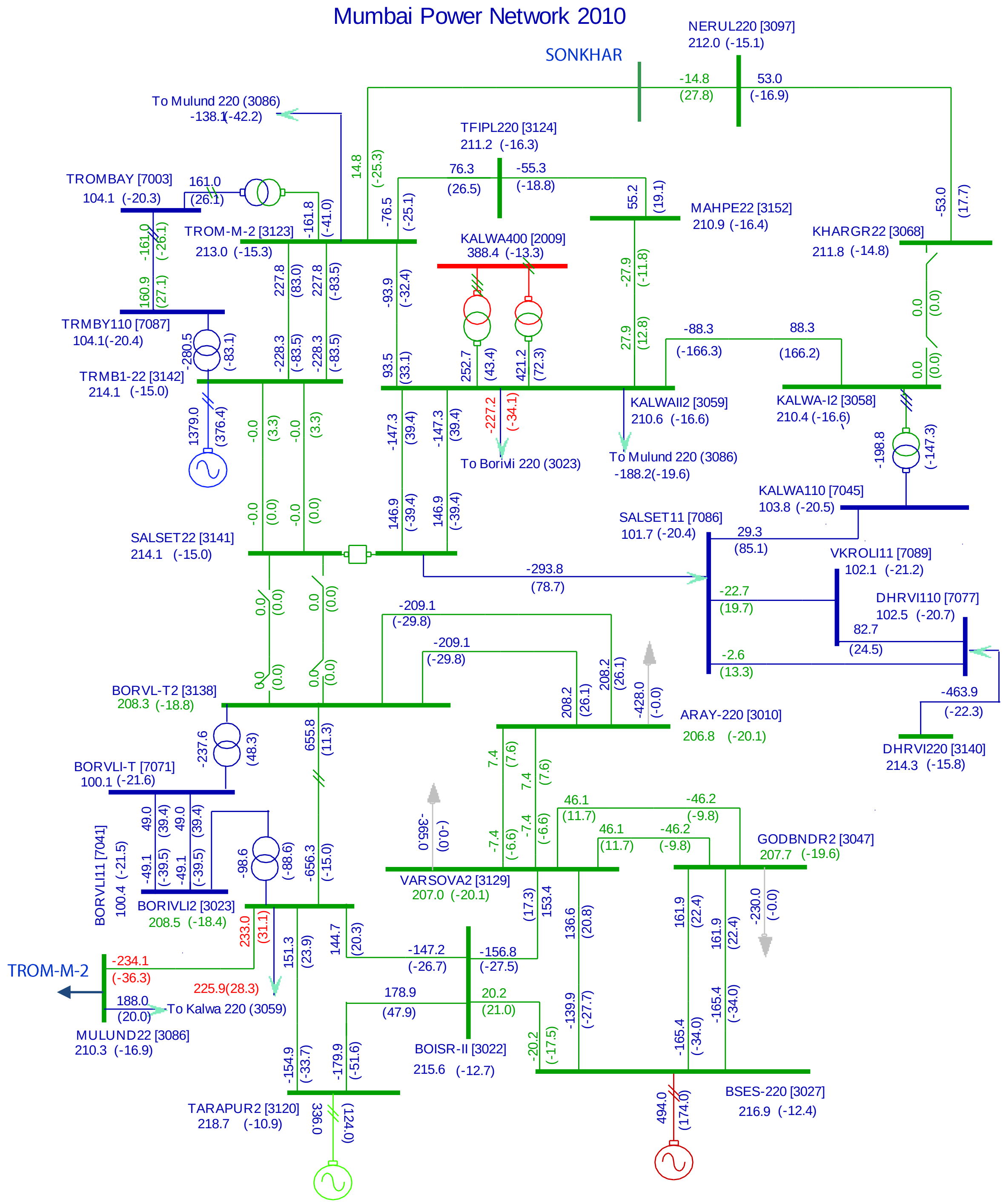

Fig. B18. Base Case of Scenario-3 with Borivali – Salsette 1&2 ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Borivali –Aarey-1 Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Aarey-Borivali 2nd ckt is over loaded with more than 400 MW.
- Flow in rest of the network is marginally affected.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- Aarey-Borivali 2nd ckt is over loaded with more than 400 MW.
- Flow in rest of the network is marginally affected.

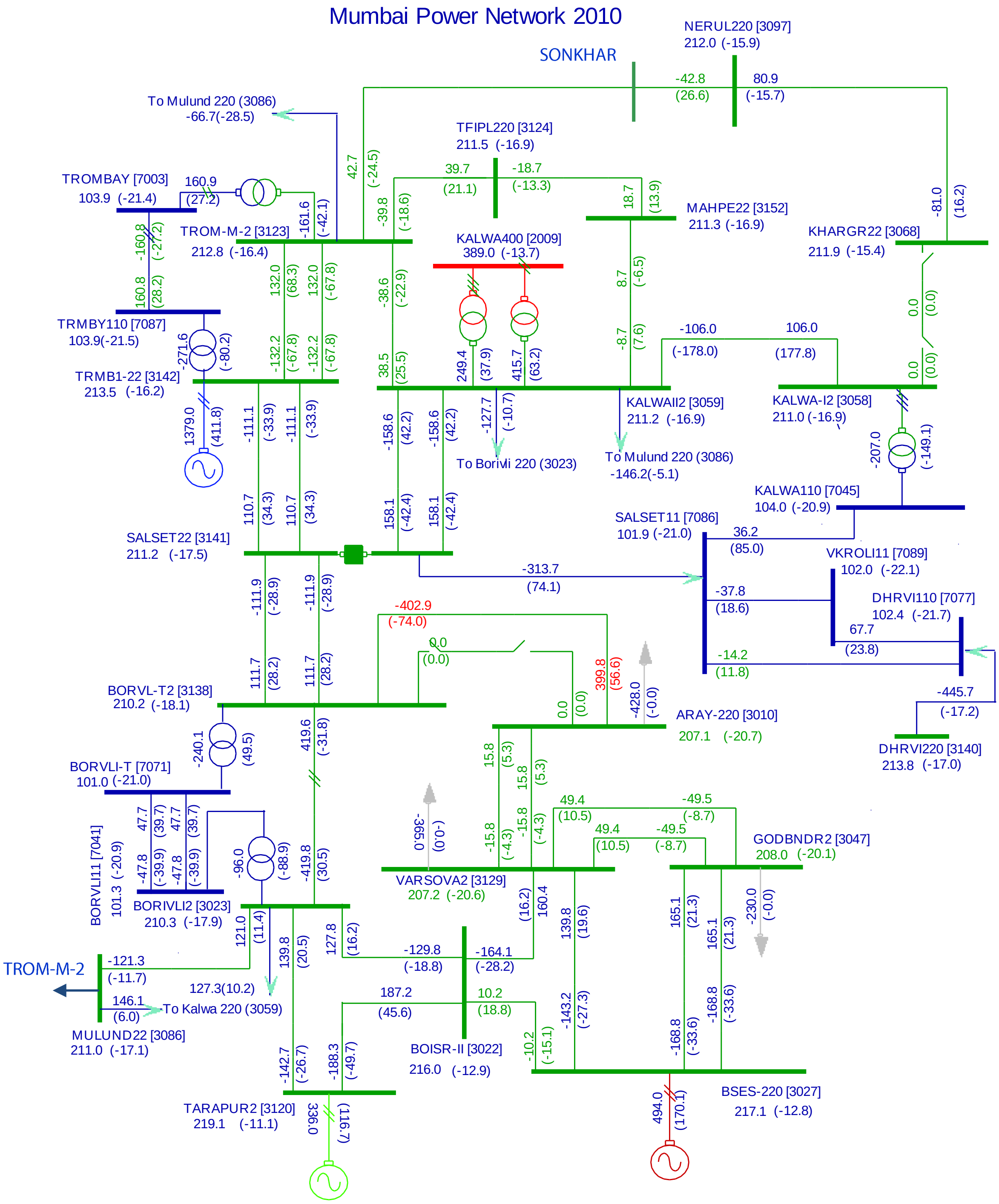

Fig. B19. Base Case of Scenario-1 with Borivali – Aarey ckt 1 out

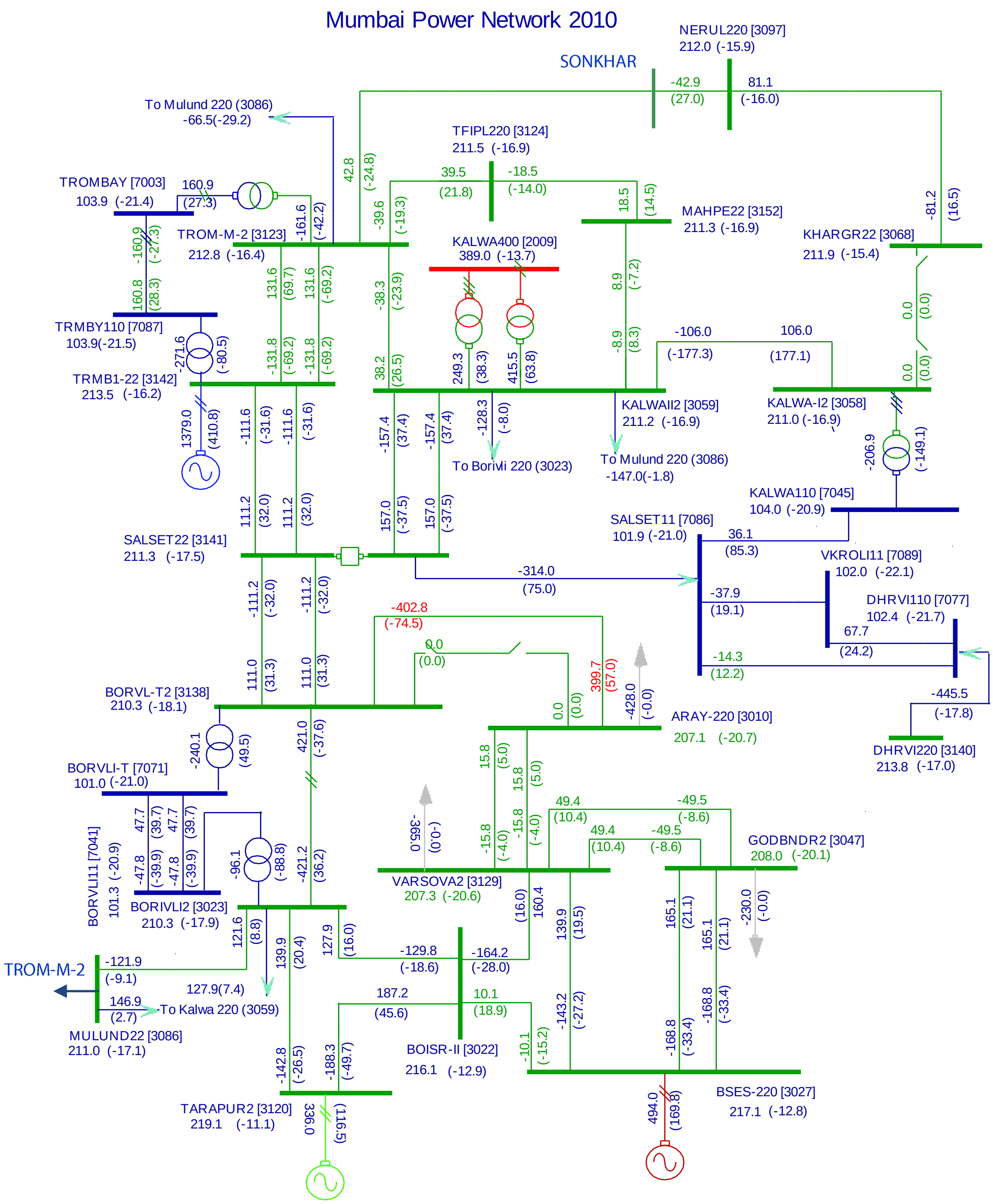

Fig. B20. Base Case of Scenario-3 with Borivali – Aarey ckt 1 out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Boisar – Varsova Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Aarey-Borivali overloaded with each circuit carring 267 MW.
- Aareay-Varsova line supports varsova load carrying more than 50 MW.
- Flow in rest of the network is marginally affected.
- Flow on Borivali-Borivali lines increase approximately by 50 MW.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- Aarey-Borivali overloaded with each circuit carring 267 MW.
- Aareay-Varsova line supports varsova load carrying more than 50 MW.
- Flow in rest of the network is marginally affected.
- Flow on Borivali-Borivali lines increase approximately by 50 MW.

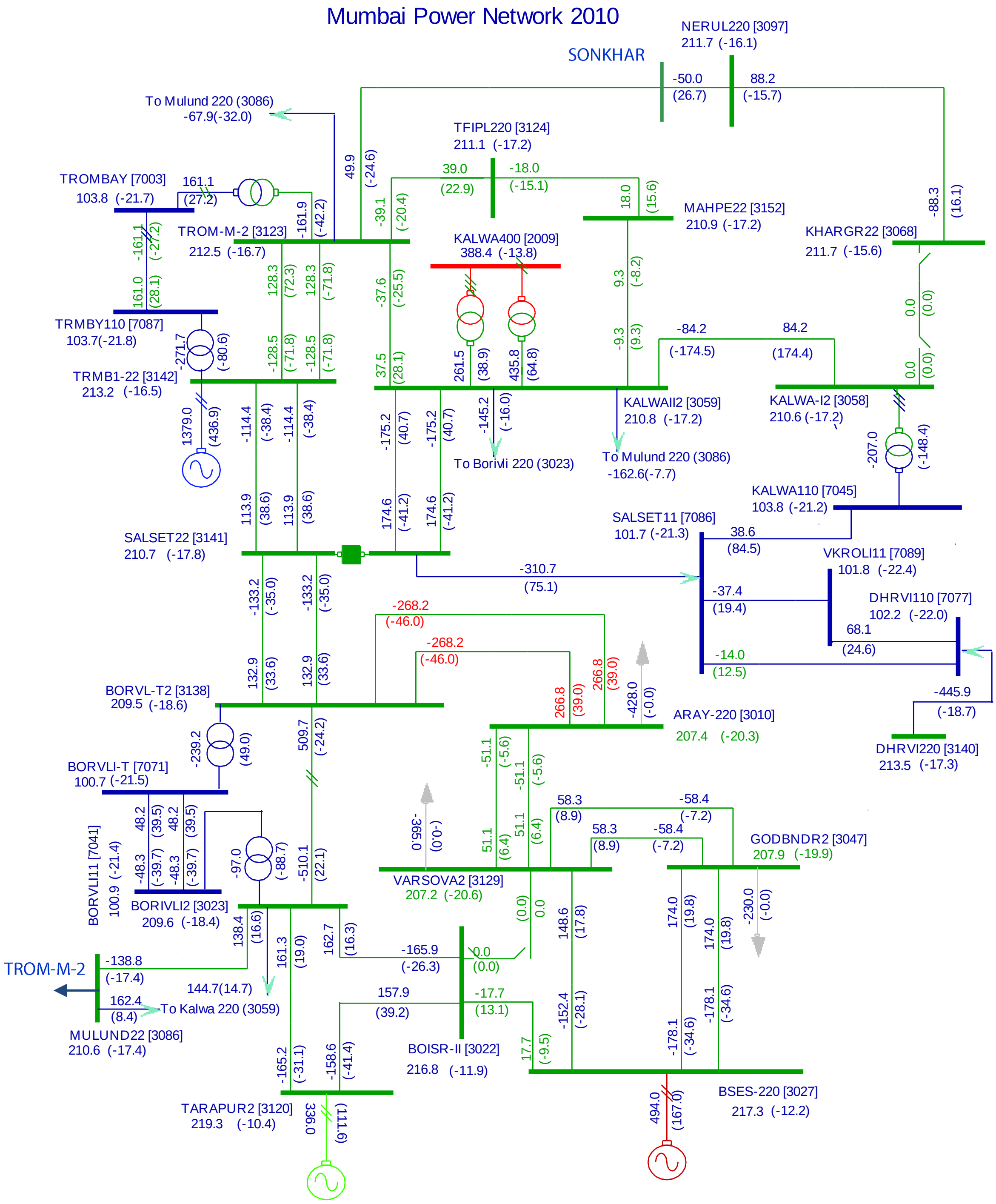

Fig. B21. Base Case of Scenario-1 with Boisar – Varsova ckt out

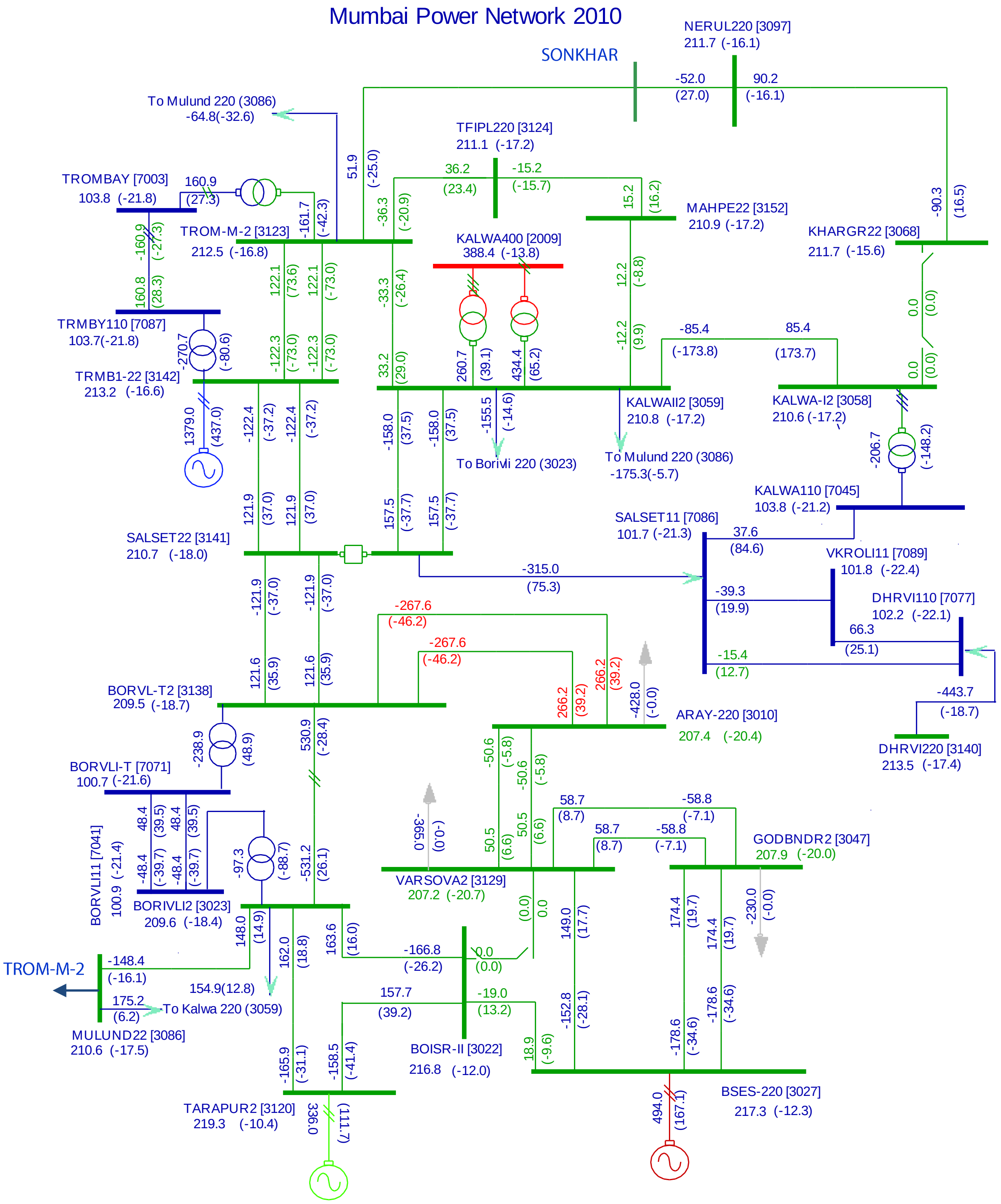

Fig. B22. Base Case of Scenario-3 with Boisar – Varsova ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Dahanu – Varsova Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Aarey-Borivali touches loading limit, carries 243 MW.
- Loading of Aarey-Varsova and Ghodbundar-Varsova increase marginally.
- Loding of rest of the network is within limit.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- Aarey-Borivali touches loading limit, carries 243 MW.
- Loding of rest of the network is within limit.
- Loading of Aarey-Varsova and Ghodbundar-Varsova increase marginally.

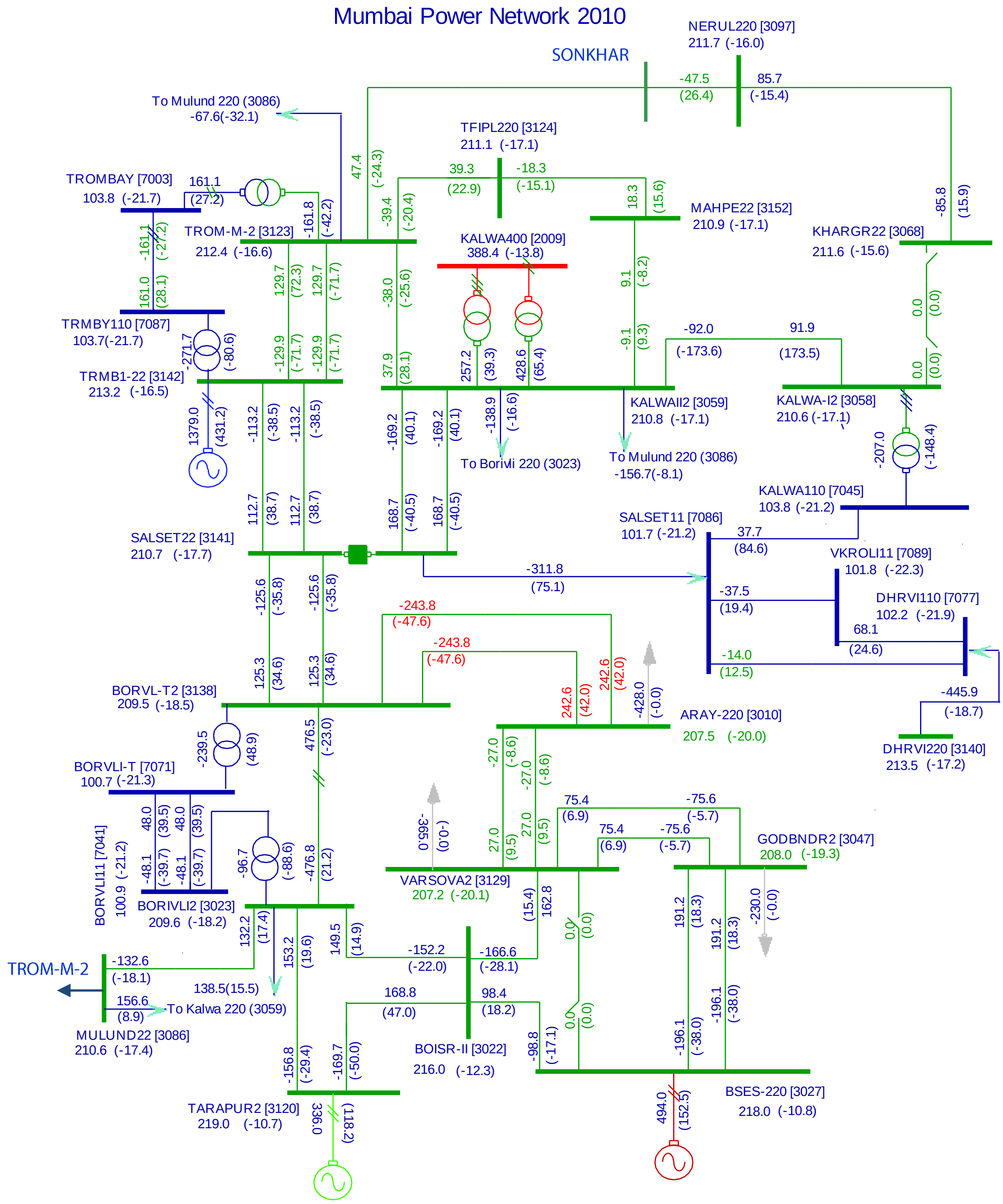

Fig. B23. Base Case of Scenario-1 with Dahanu – Varsova ckt out

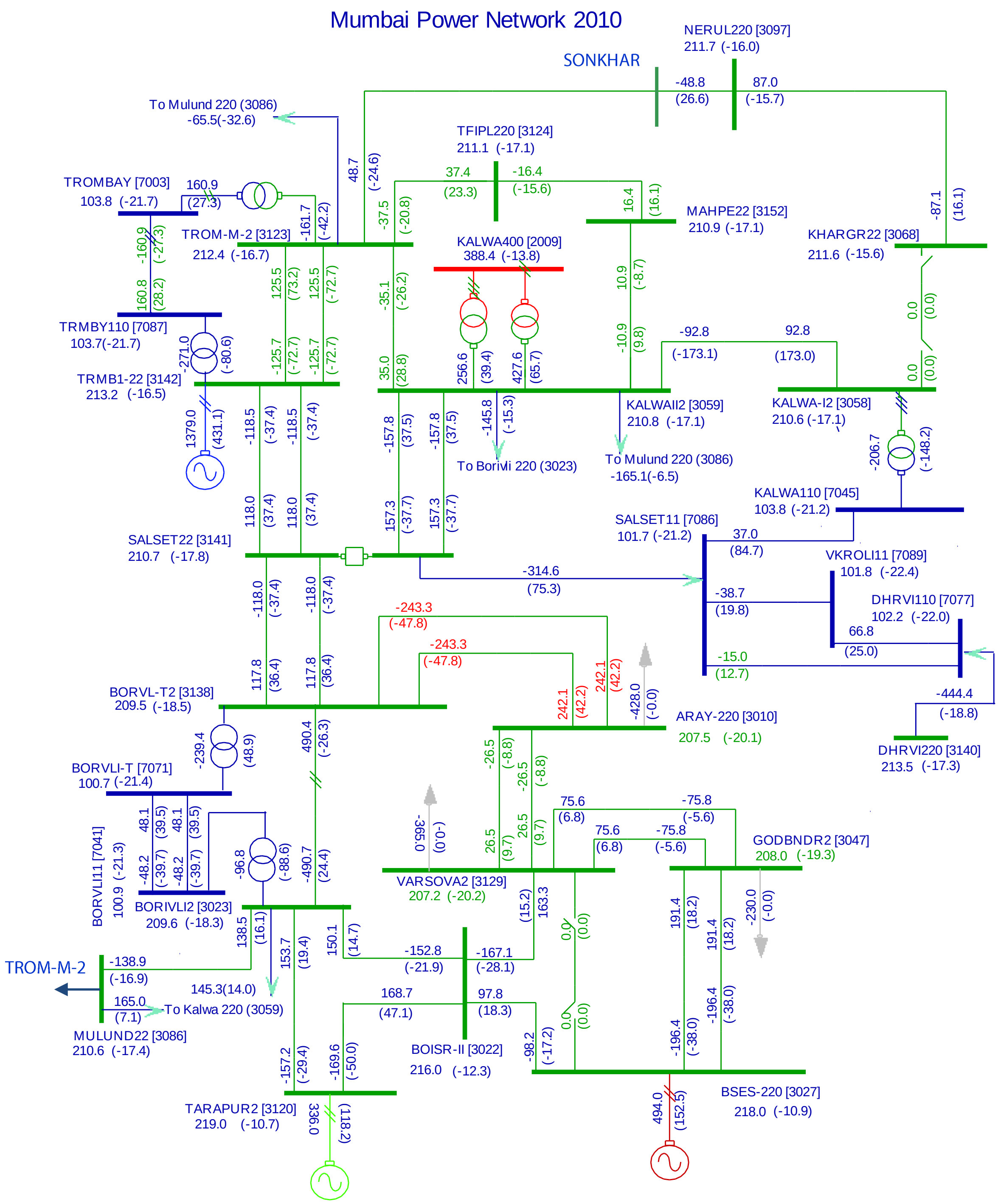

Fig. B24. Base Case of Scenario-3 with Dahanu – Varsova ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Dahanu –Boisar Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Flow over all the lines change marginally and within limit.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- Flow over all the lines change marginally and within limit.

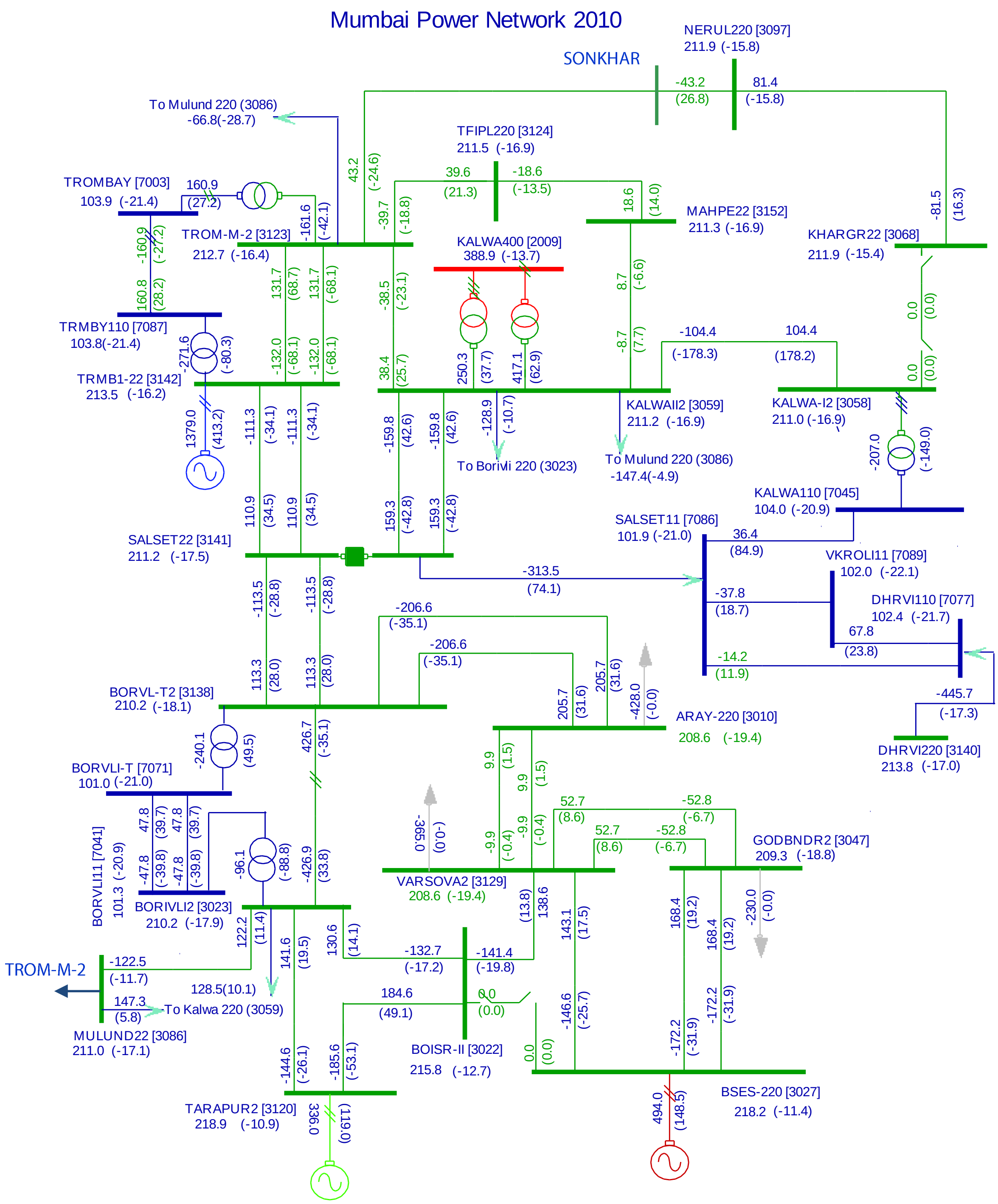

Fig. B25. Base Case of Scenario-1 with Dahanu –Bosiar ckt out

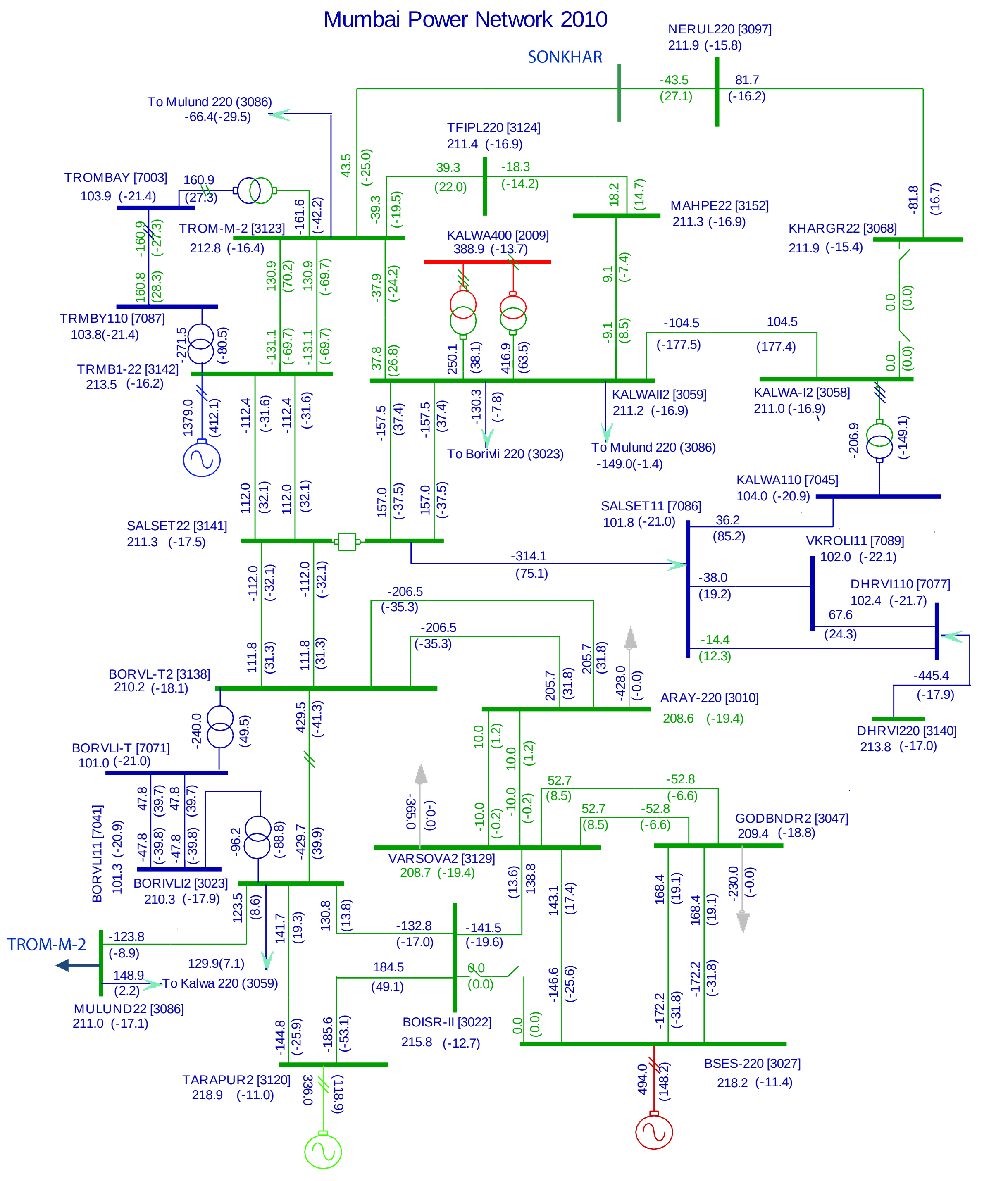

Fig. B26. Base Case of Scenario-1 with Dahanu –Bosiar ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Borivali –Kalwa-1 Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Flow over all the lines change marginally and within limit.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- Flow over all the lines change marginally and within limit except Borivali – Mulund 220 kV line carrying 224 MW.

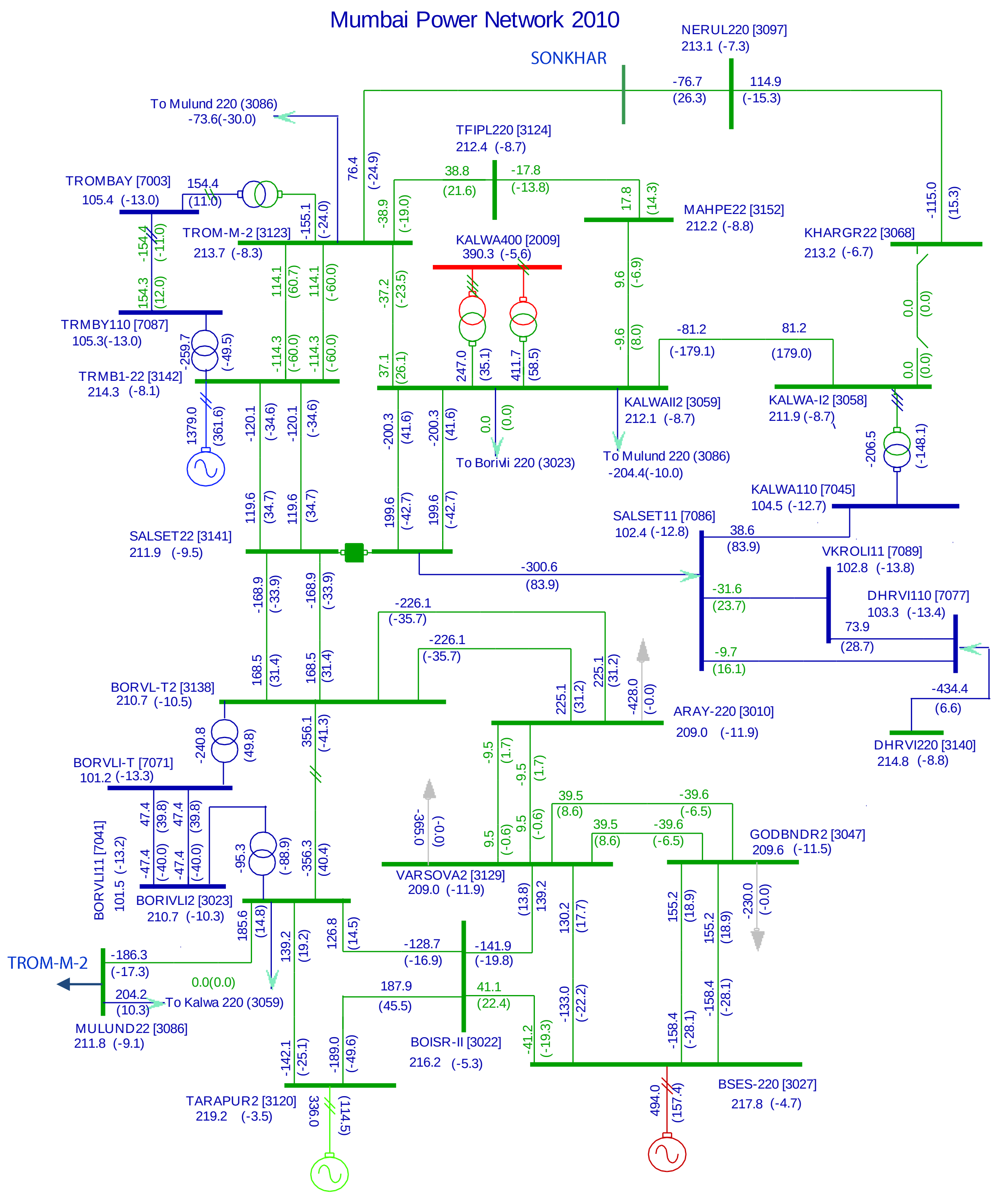

Fig. B27. Base Case of Scenario-1 with Borivali–Kalwa ckt out

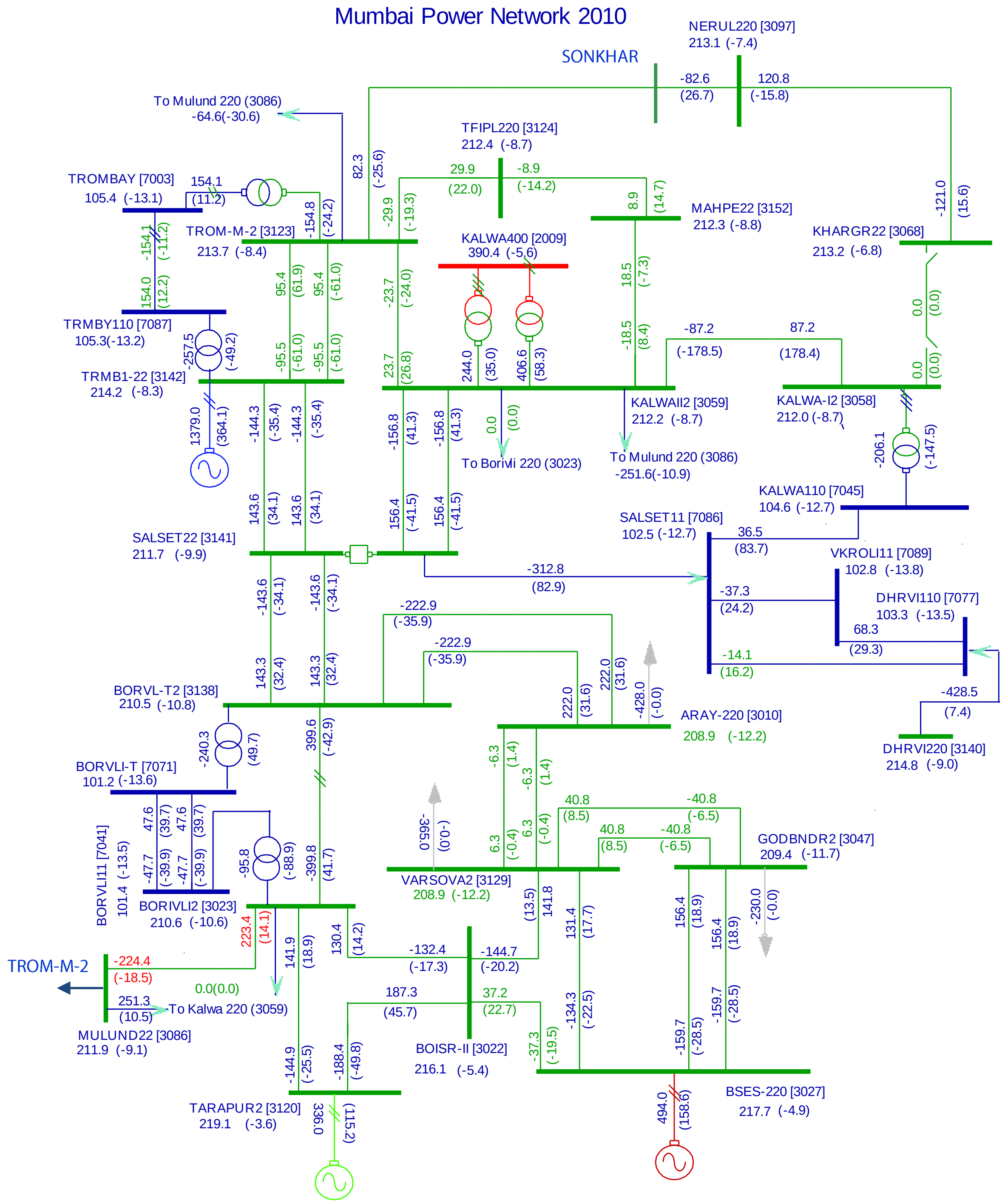

Fig. B28. Base Case of Scenario-3 with Borivali–Kalwa ckt out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Dahanu Unit-1 Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Aarey-Borivali line gets over loaded carrying more than 273 MW.
- Flow over rest of the lines change marginally and within limit.
- Flow reversal on Boisar-Dahanu 220 kV line is observed.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- Aarey-Borivali line gets over loaded carrying more than 273 MW.
- Flow over rest of the lines change marginally and within limit.
- Flow reversal on Boisar-Dahanu 220 kV line is observed.

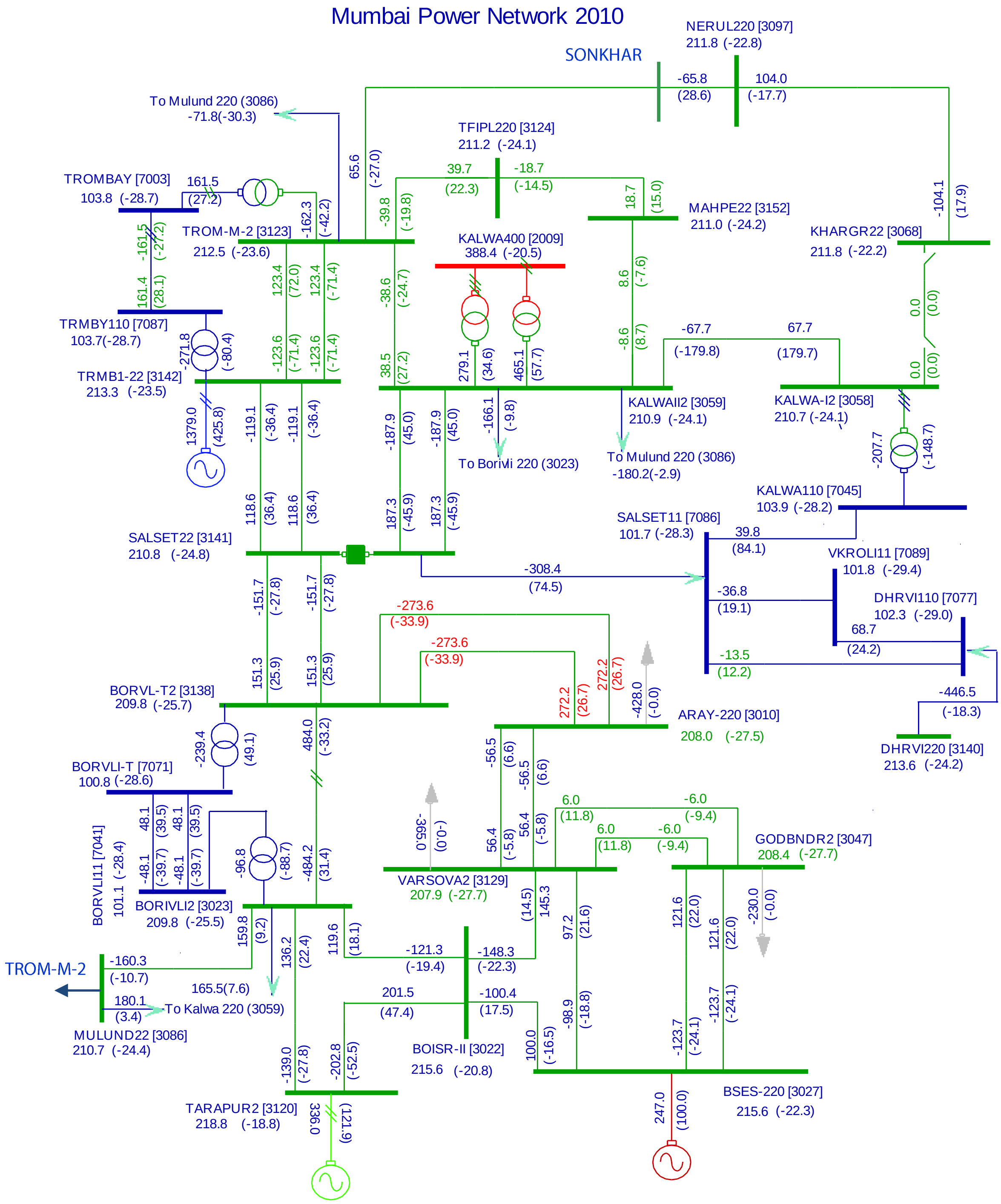

Fig. B29. Base Case of Scenario-1 with Dahanu unit-1 out

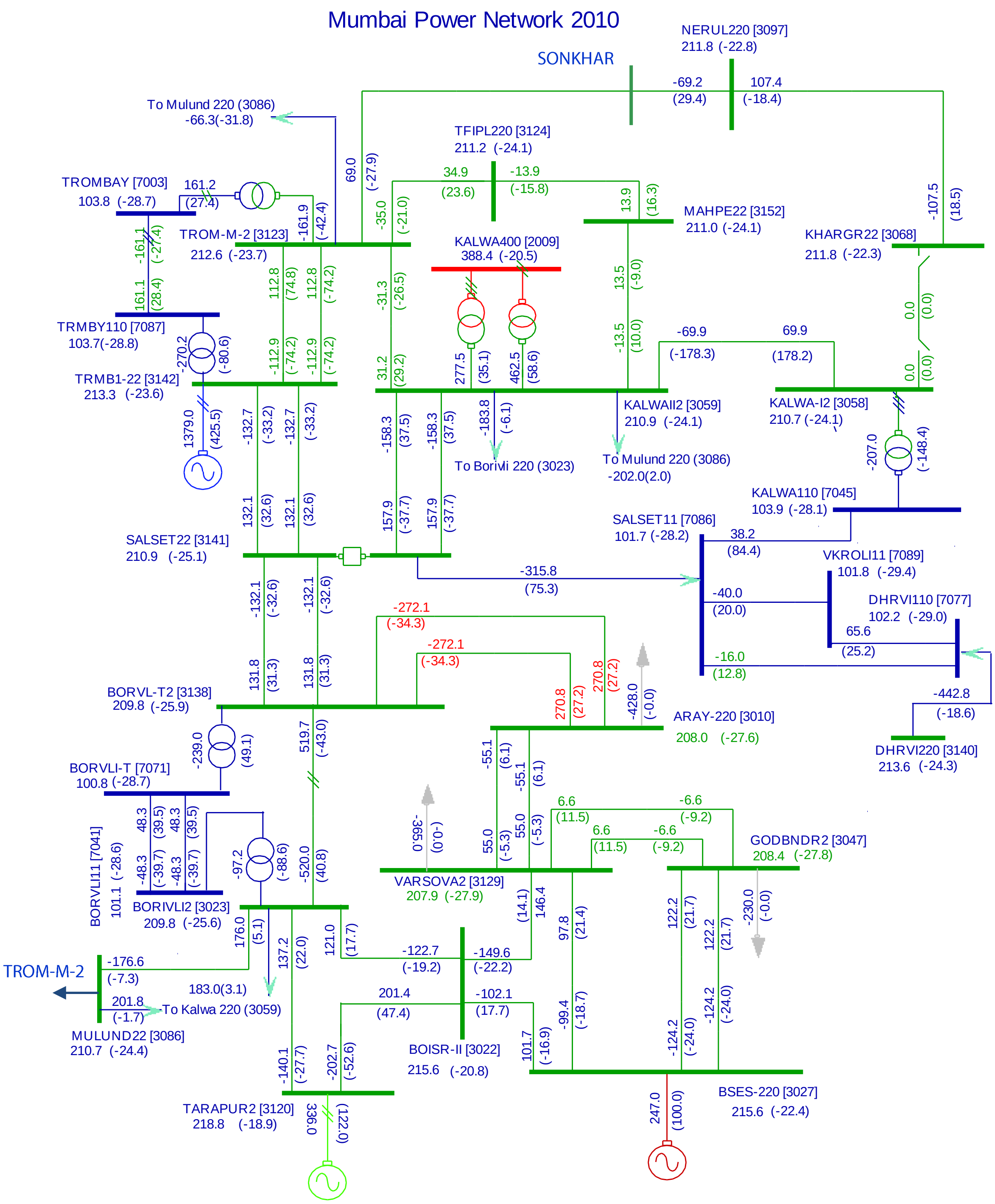

Fig. B30. Base Case of Scenario-3 with Dahanu unit-1 out

Borivali-Borivali 220 kV In Service	Salsette Bus Coupler In Service	Borivali-Borivali 220 kV In Service	Salsette Bus Coupler not in Service
Scenario-1		Scenario-3	
Trombay Unit-5 Out			

With Borivali-Borivali 220 kV line in service and Salsette B/C in service

- Kalwa ICT carries more than 850 MW.
- Borivali-Borivali corridor is loaded with 470 MW.
- Flow over rest of the lines change marginally and within limit.
- Flow over Kharghar-Nerul 220 kV line increse from 86 MW (in base case) to 171 MW.

With Borivali-Borivali 220 kV line in service and Salsette B/C out of service

- Kalwa ICT carries more than 850 MW.
- Borivali-Borivali corridor is loaded with 536 MW.
- Flow over rest of the lines change marginally and within limit. Flow over Kharghar-Nerul 220 kV line increse from 86 MW (in base case) to 177 MW.

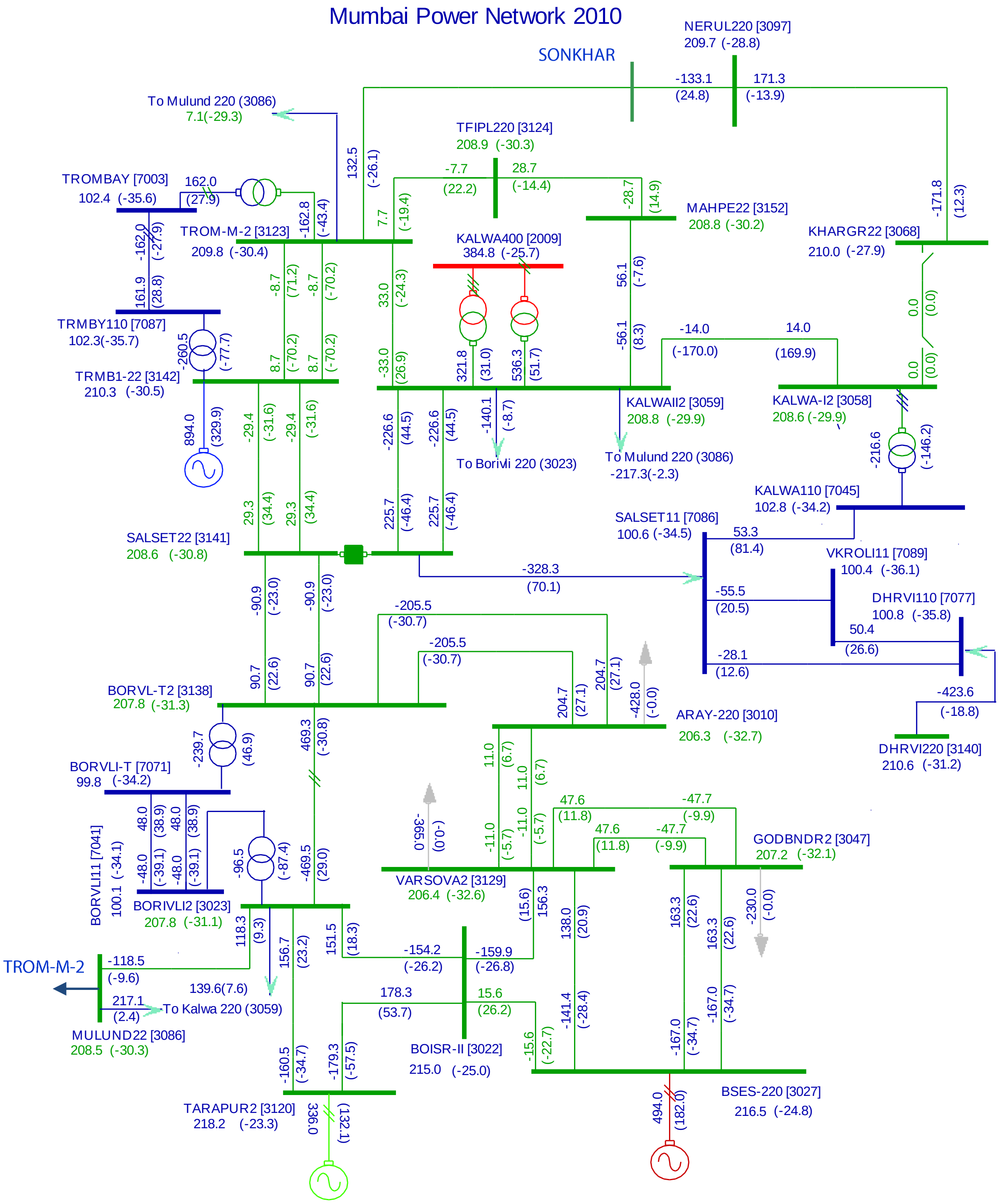

Fig. B31. Base Case of Scenario-1 with Trombay unit-5 out

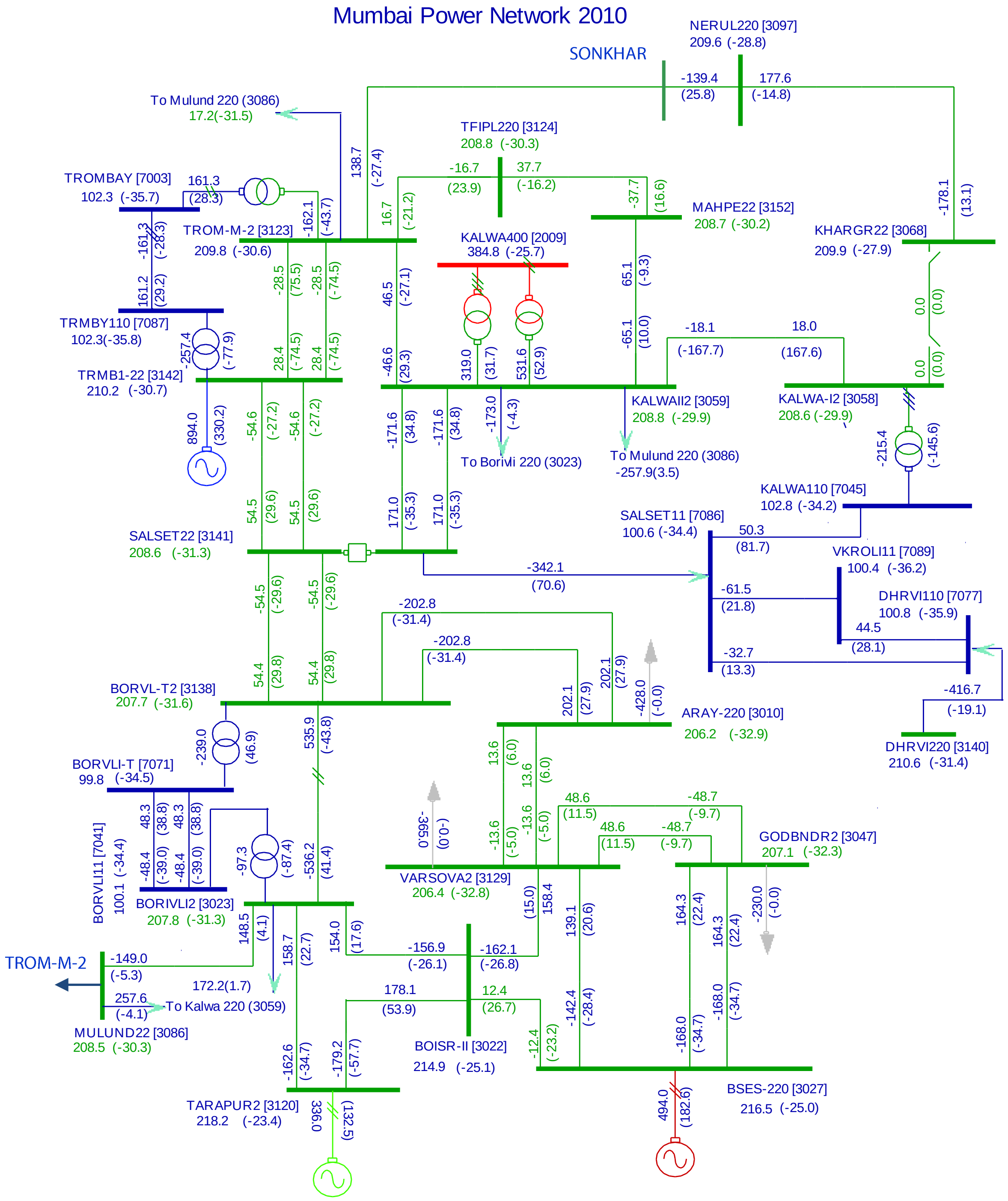

Fig. B32. Base Case of Scenario-3 with Trombay unit-5 out

Annexure – C

Contingency Studies and Results of Augmented Mumbai Network

Contingency Number	**Outages**
	Base Case
1	Trombay-Salsette 220 kV ckt 1out
2	Trombay-Salsette 220 kV ckt 1 and 2 out
3	Kalwa-Salsette 220 kV ckt 3 out
4	Kalwa-salsette 220 kV ckt 3 and 4 out
5	Dahanu – Ghodbundar 220 kV ckt 1out
6	Dahanu – Ghodbundar 220 kV ckt 1 and 2 out
7	Borivali-Salsette 220 kV ckt 1out
8	Borivali-Salsette 220 kV ckt 1&2 out
9	Boisar – Broivali ckt1&2
10	Borivali-Aarey 220 kV ckt 1 out
11	Boisar-Versova 220 kV ckt out
12	Boisar-Dahanu 220 kV ckt out
13	Dahanu-Varsova 220 kV ckt out
14	Borivali-Kalwa 220 kV ckt out
15	Bo-Bo corridor outage
16	Dahanu unit 1 out (Not converged)
17	Trombay unit 5 out (Not converged)

Mumbai System Load Flow Analysis

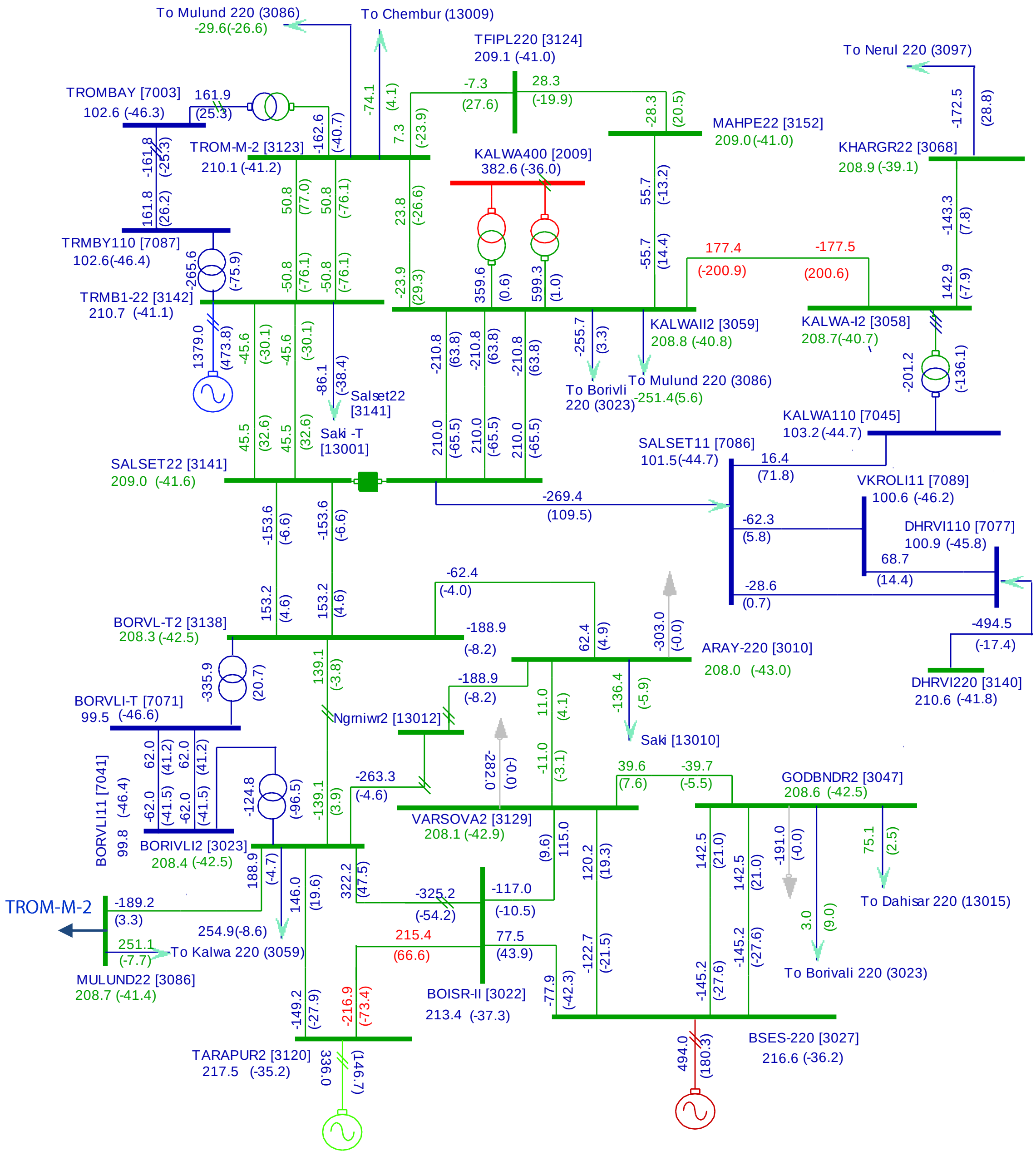

Fig. C1. Base Case of Augmented Network of Mumbai System.

Mumbai System Load Flow Analysis

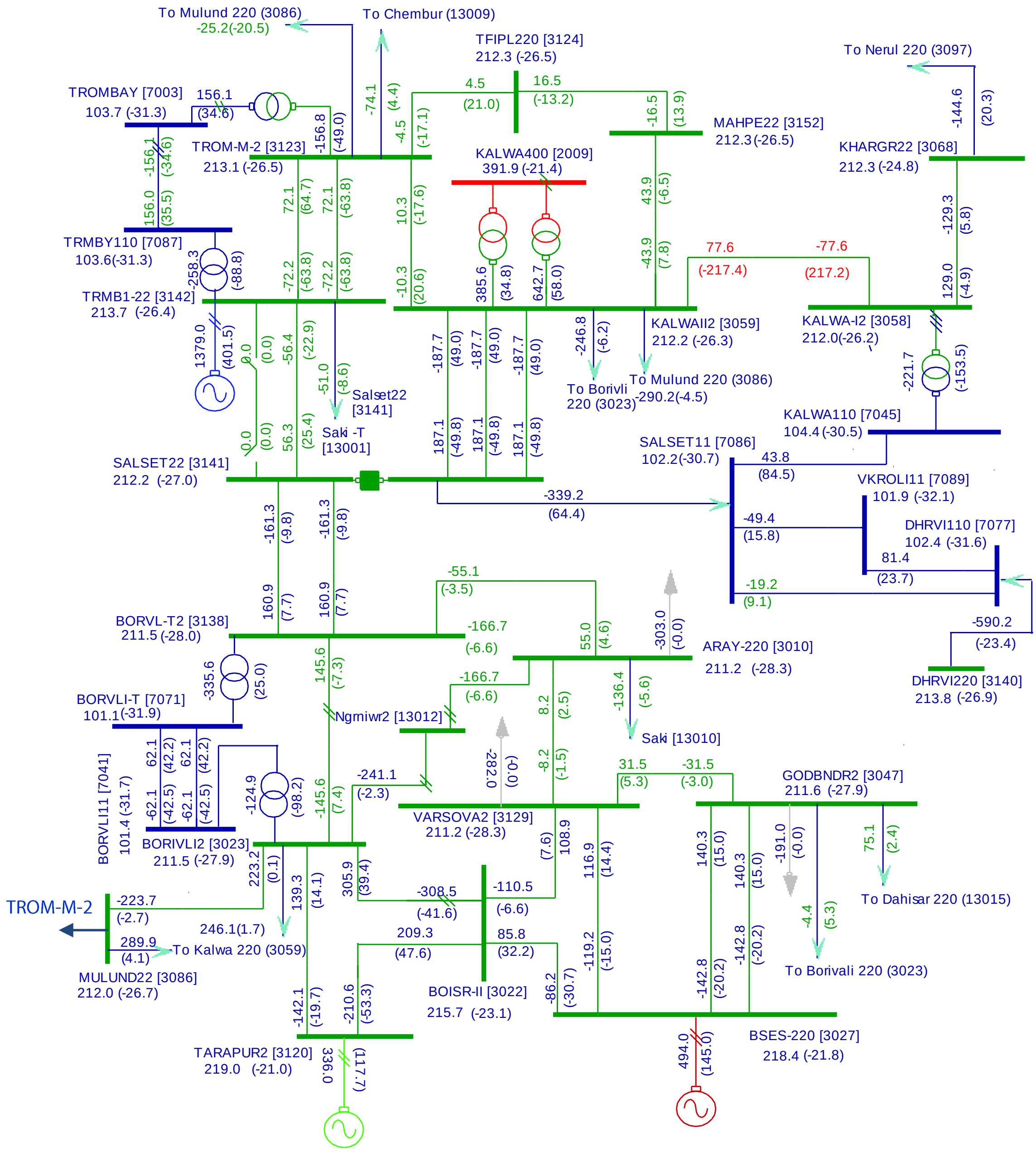

Fig. C2. Trombay – Salsette ckt 1 out

Mumbai System Load Flow Analysis

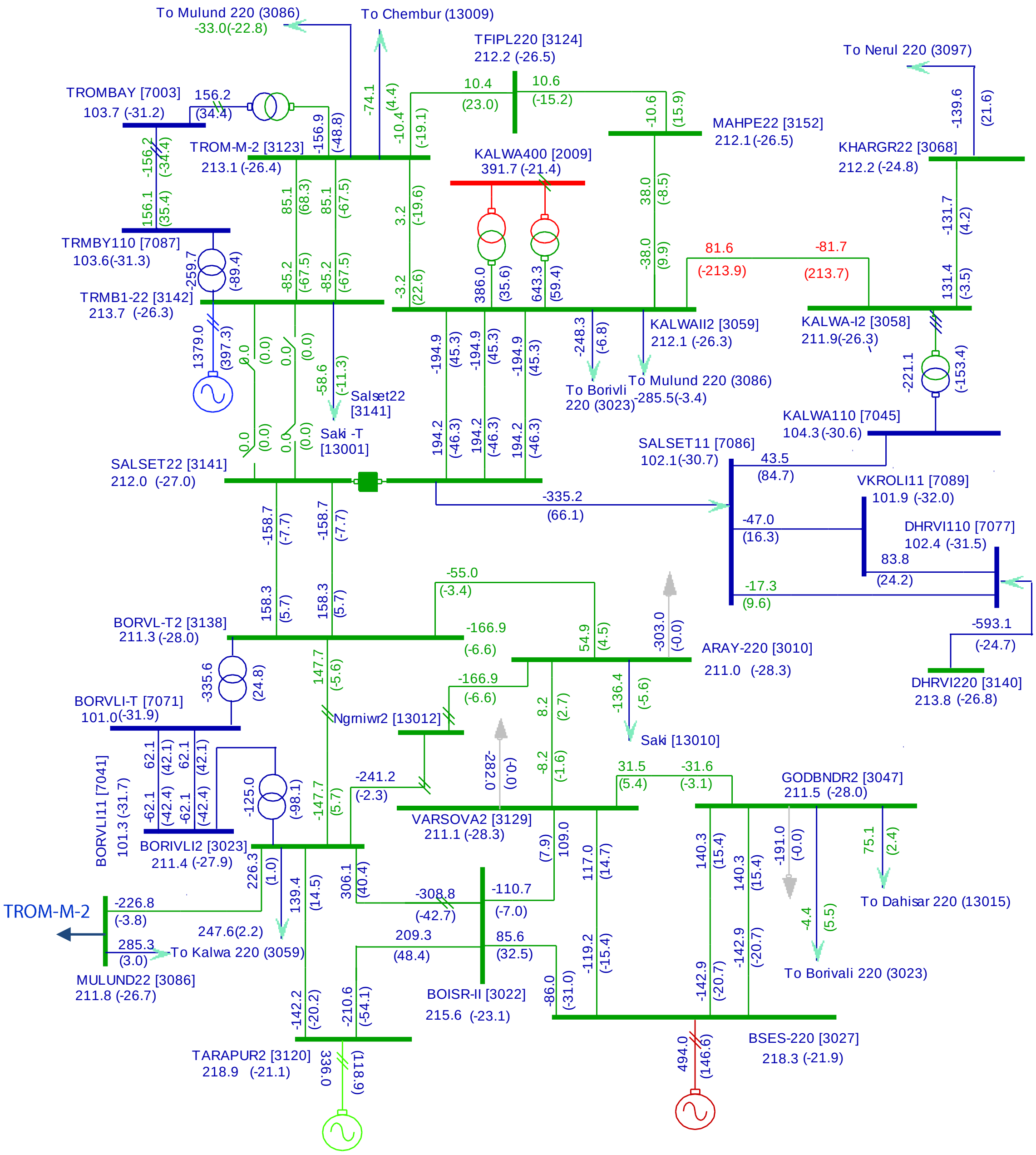

Fig. C3 Trombay – Salsette ckt 1 & 2 out

Mumbai System Load Flow Analysis

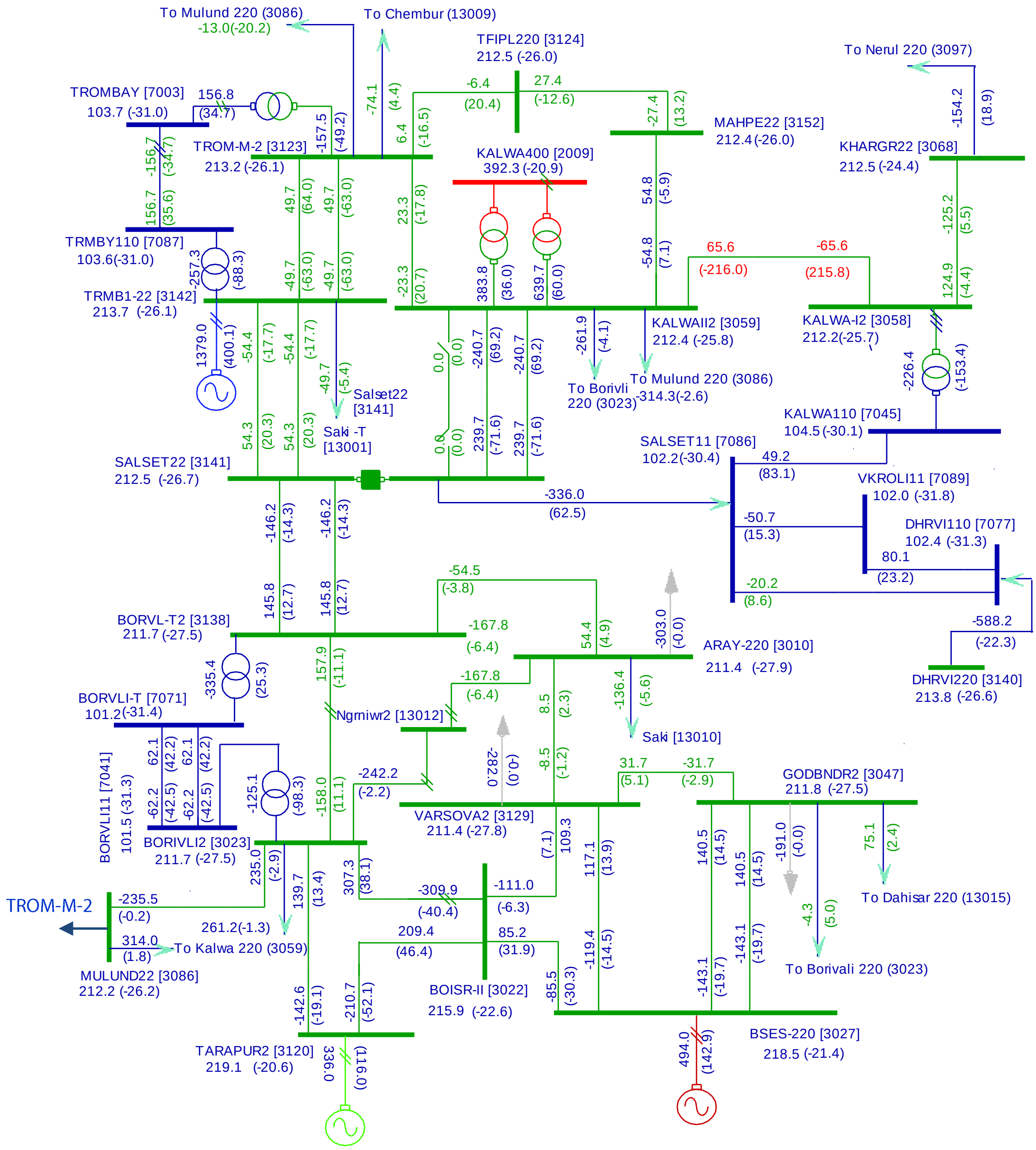

Fig. C4 Kalwa – Salsette ckt no. 3 out

Mumbai System Load Flow Analysis

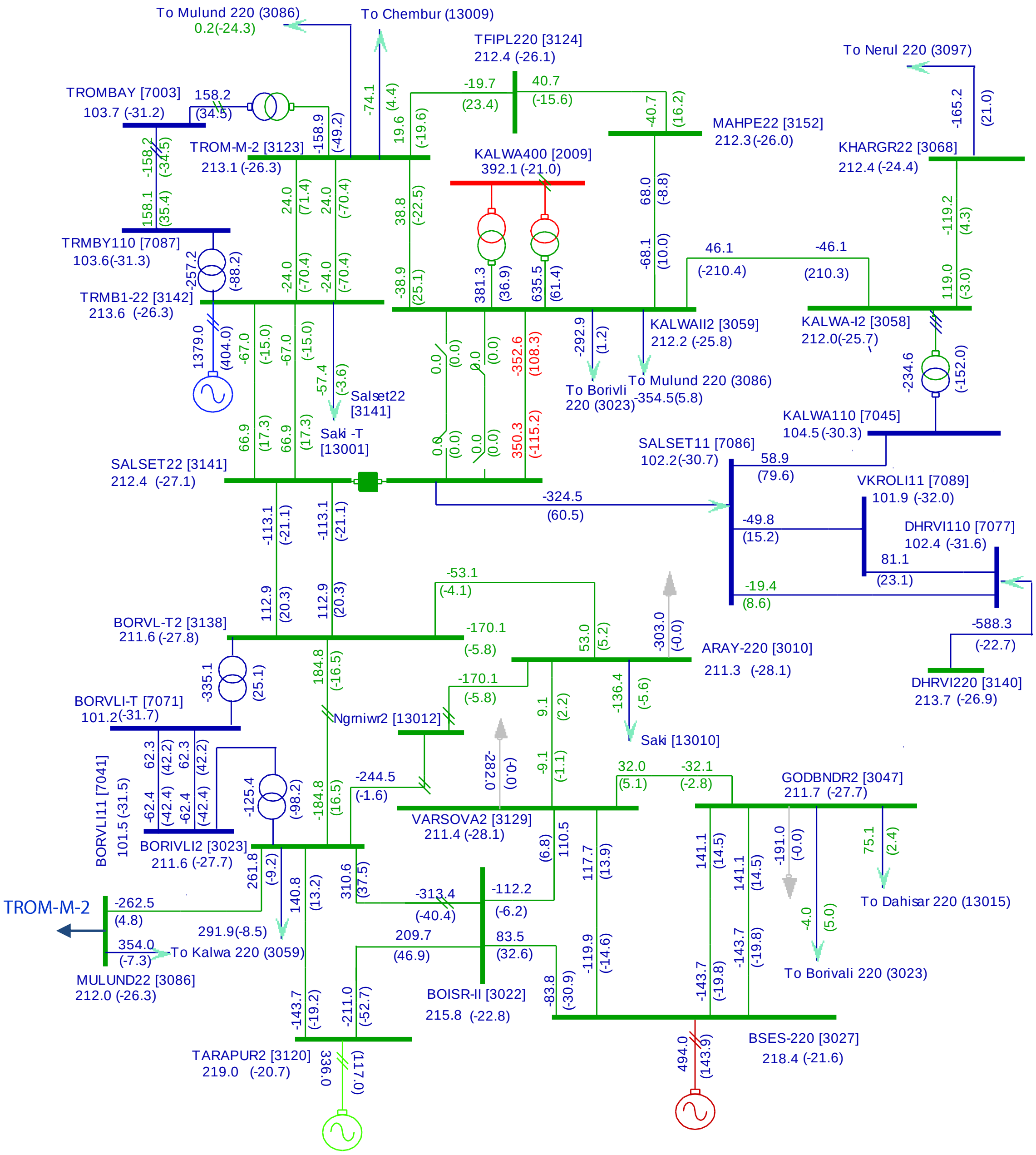

Fig. C5. Kalwa – Salsette ckt no. 3 & 4 out

Mumbai System Load Flow Analysis

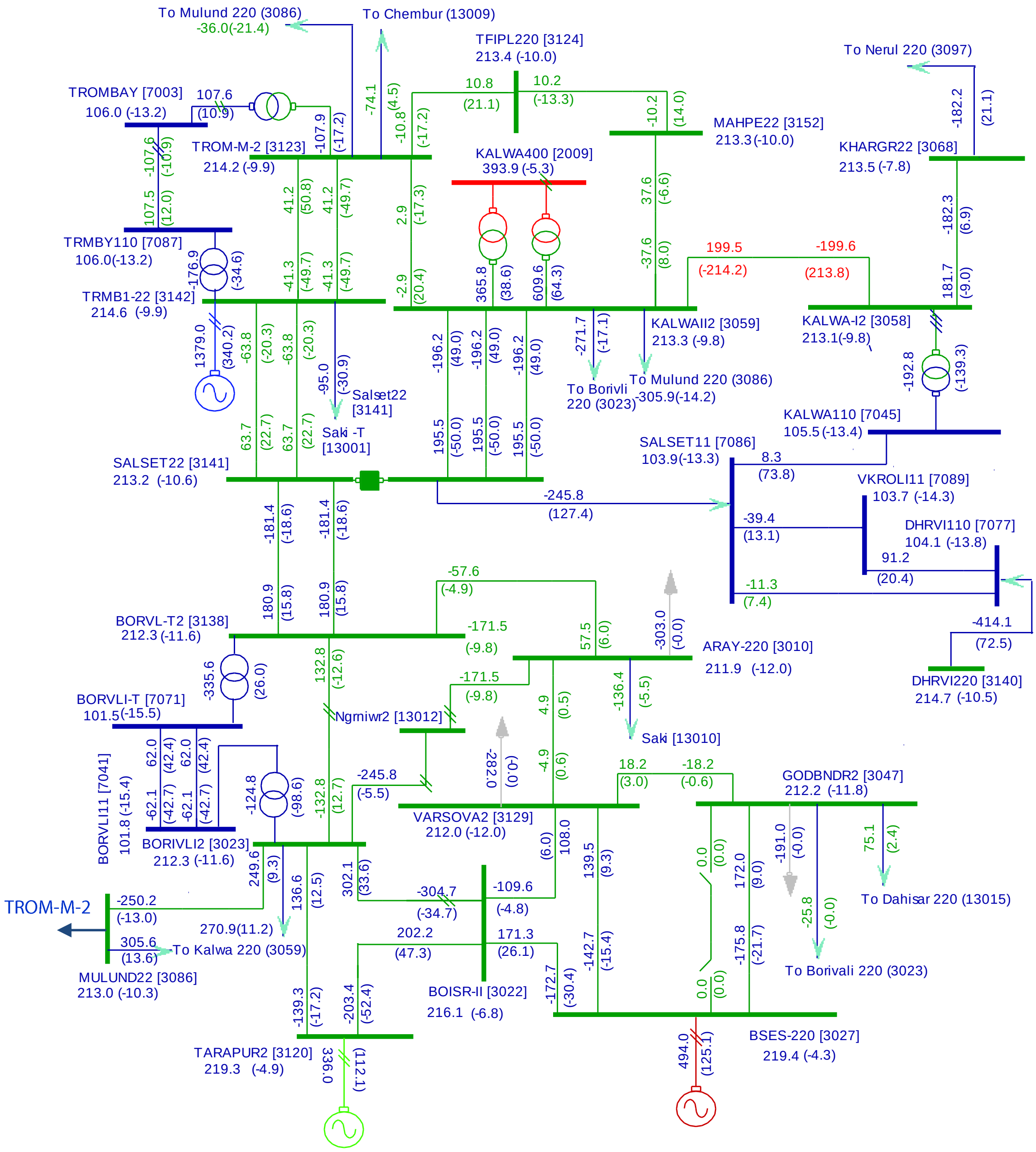

Fig. C6. Dahanu – Ghodbunder ckt 1 out

Mumbai System Load Flow Analysis

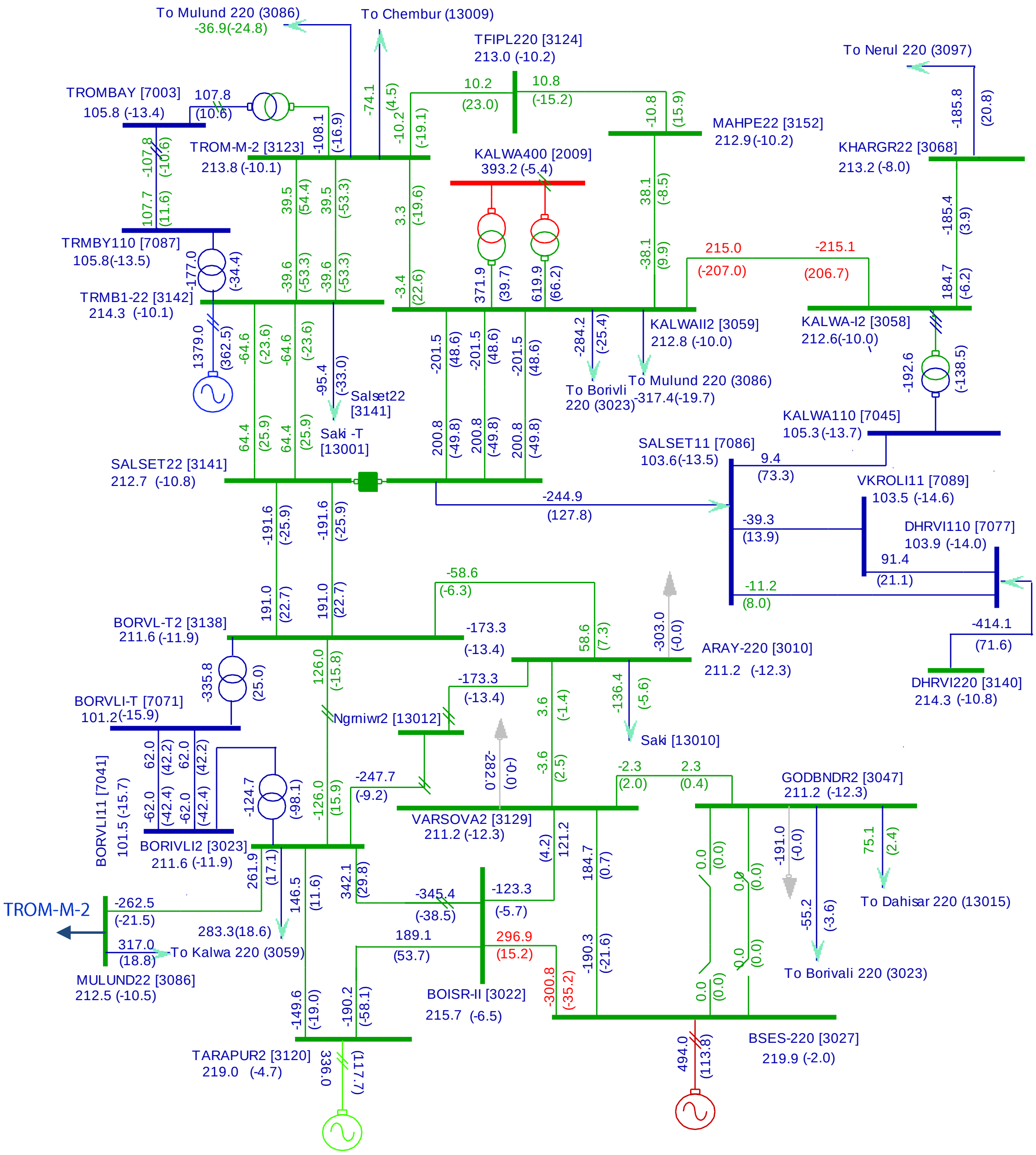

Fig. C7. Dahanu – Ghodbunder ckt 1& 2 out

Mumbai System Load Flow Analysis

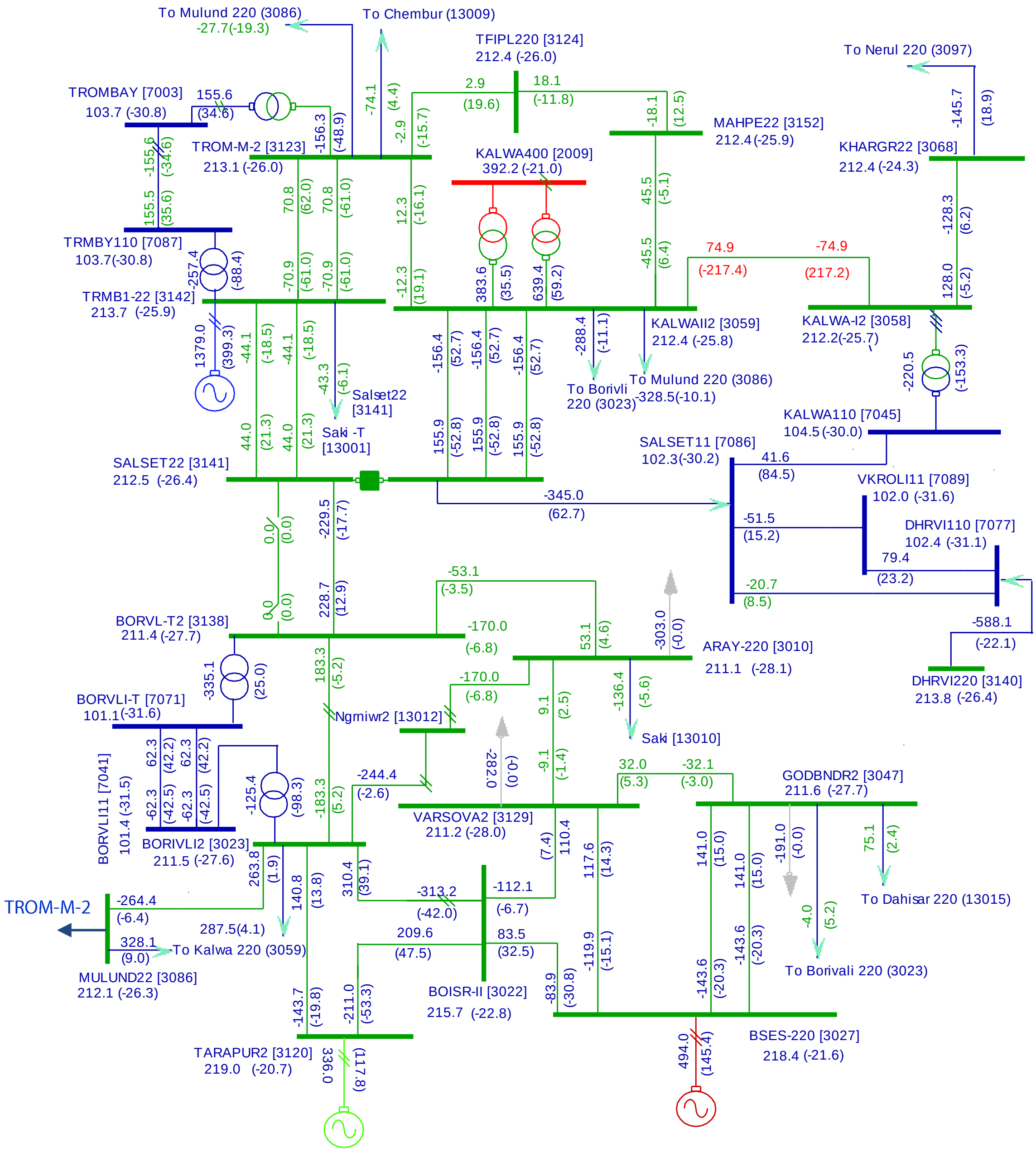

Fig. C8. Borivali – Salsette ckt 1 out

Mumbai System Load Flow Analysis

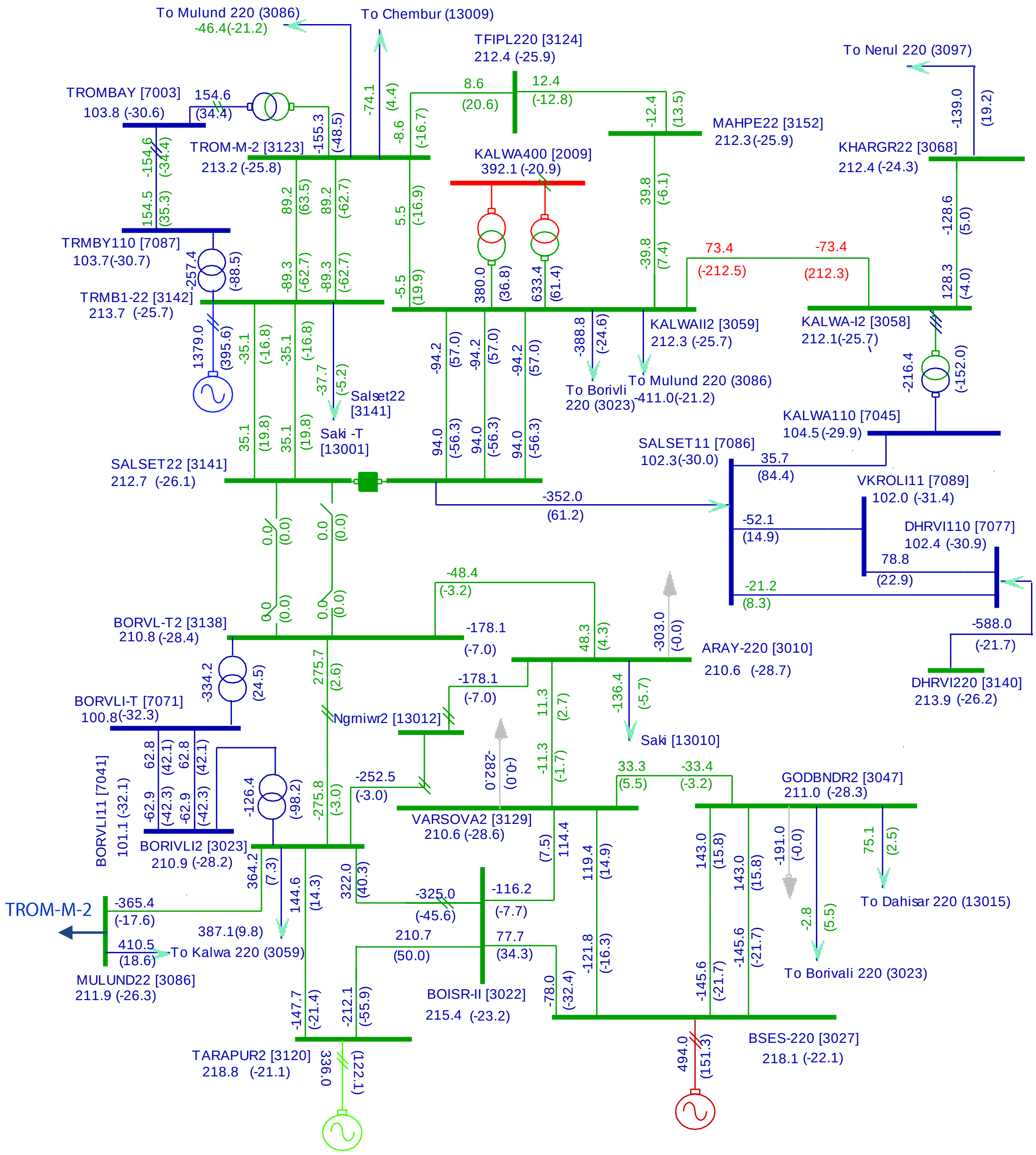

Fig. C9. Borivali – Salsette ckt 1 & 2out

Mumbai System Load Flow Analysis

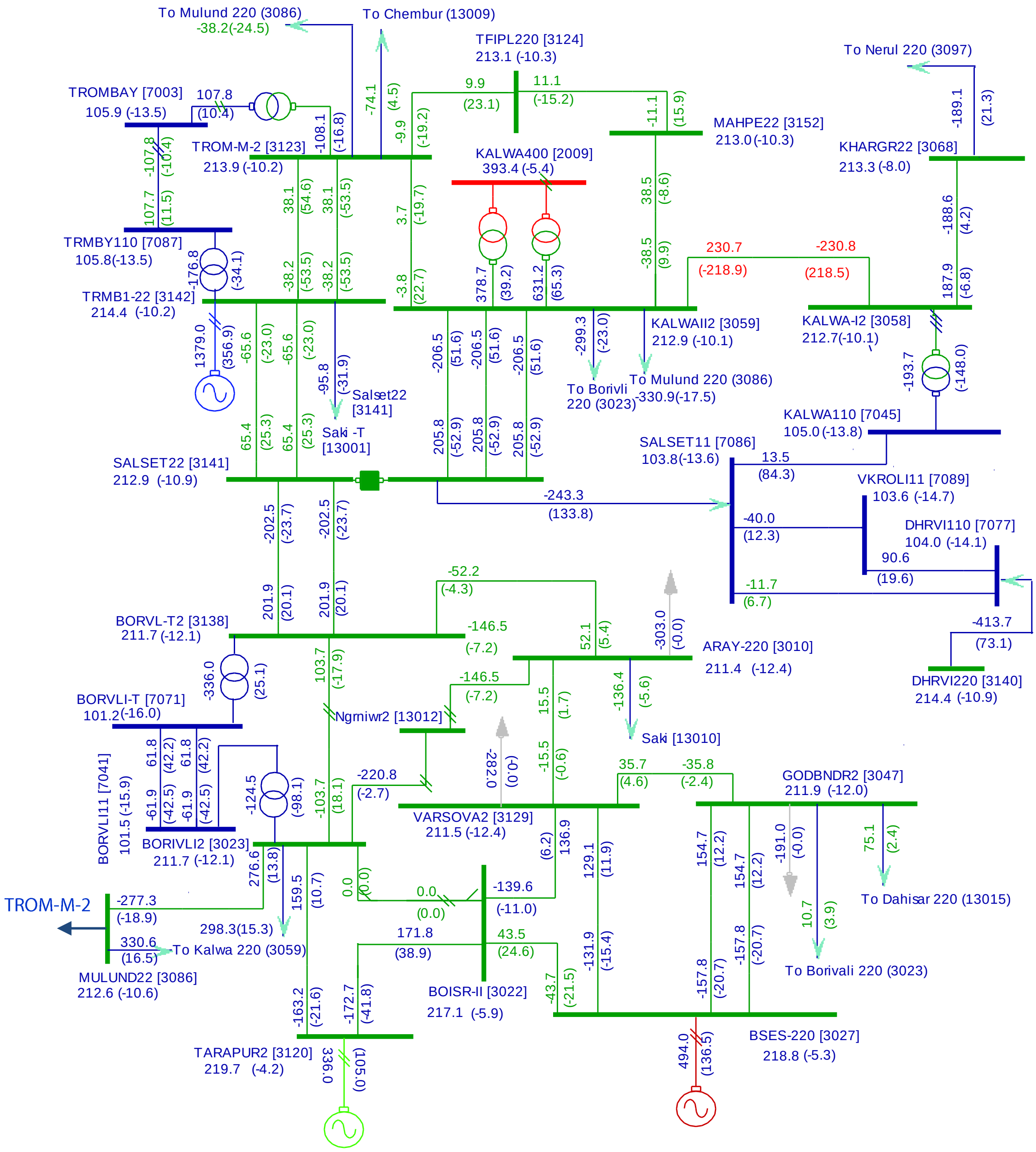

Fig. C10. Borivali – Boisar ckt 1 & 2 out

Mumbai System Load Flow Analysis

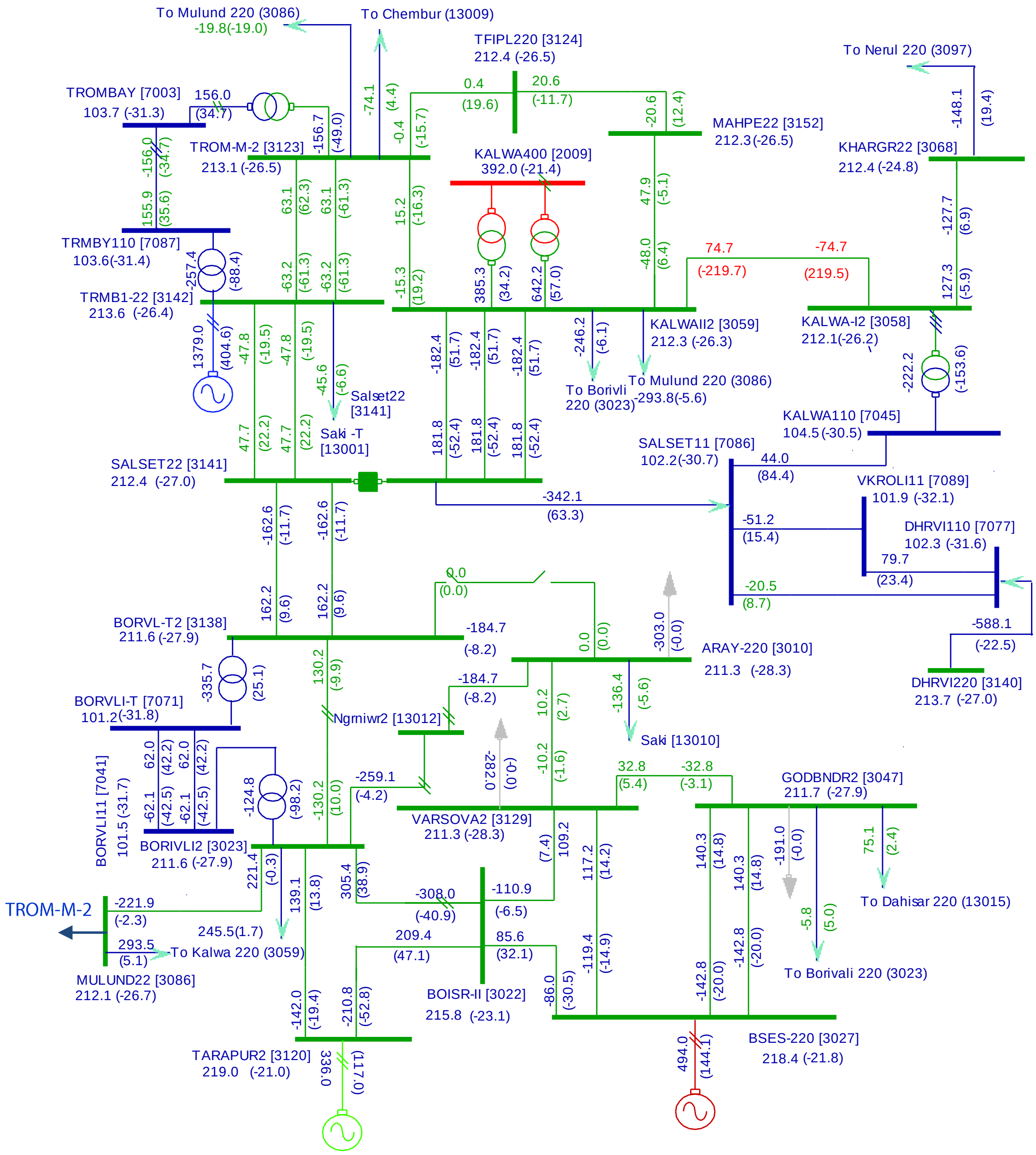

Fig. C11. Borivali – Aarey ckt 1 out

Mumbai System Load Flow Analysis

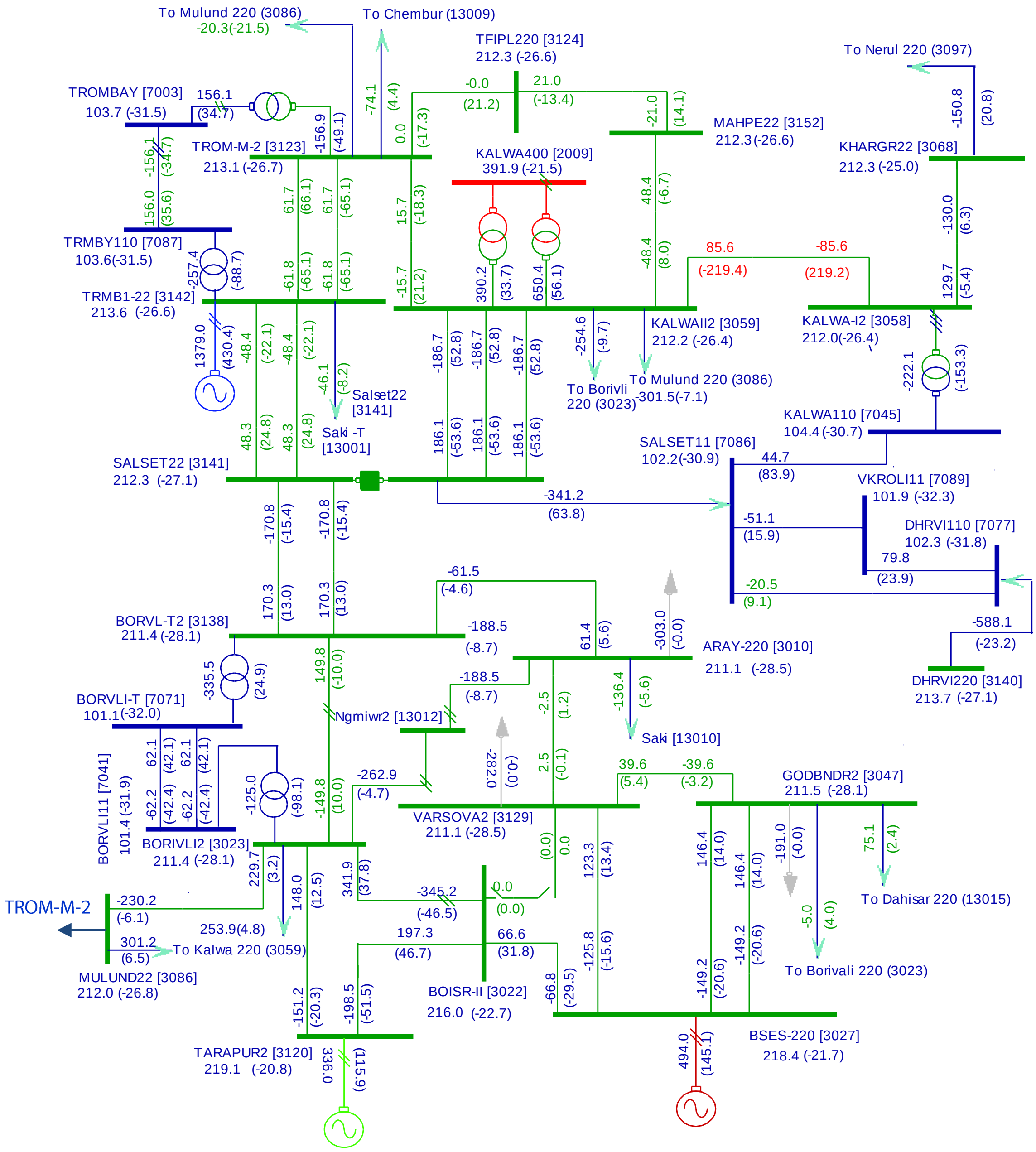

Fig. C12. Boisar – Varsova ckt 1 out

Mumbai System Load Flow Analysis

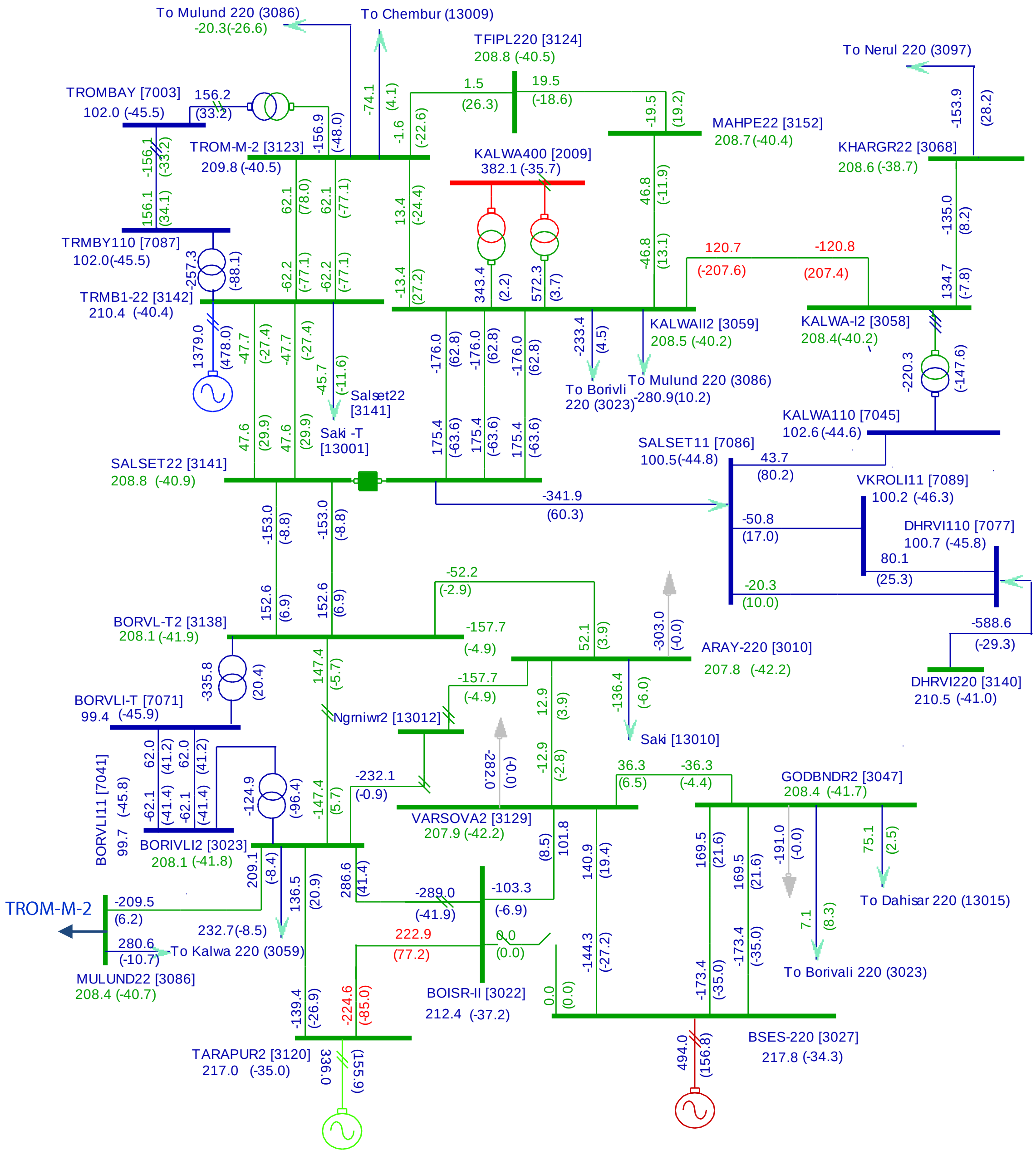

Fig. C13. Dahanu – Boisar ckt 1 out

Mumbai System Load Flow Analysis

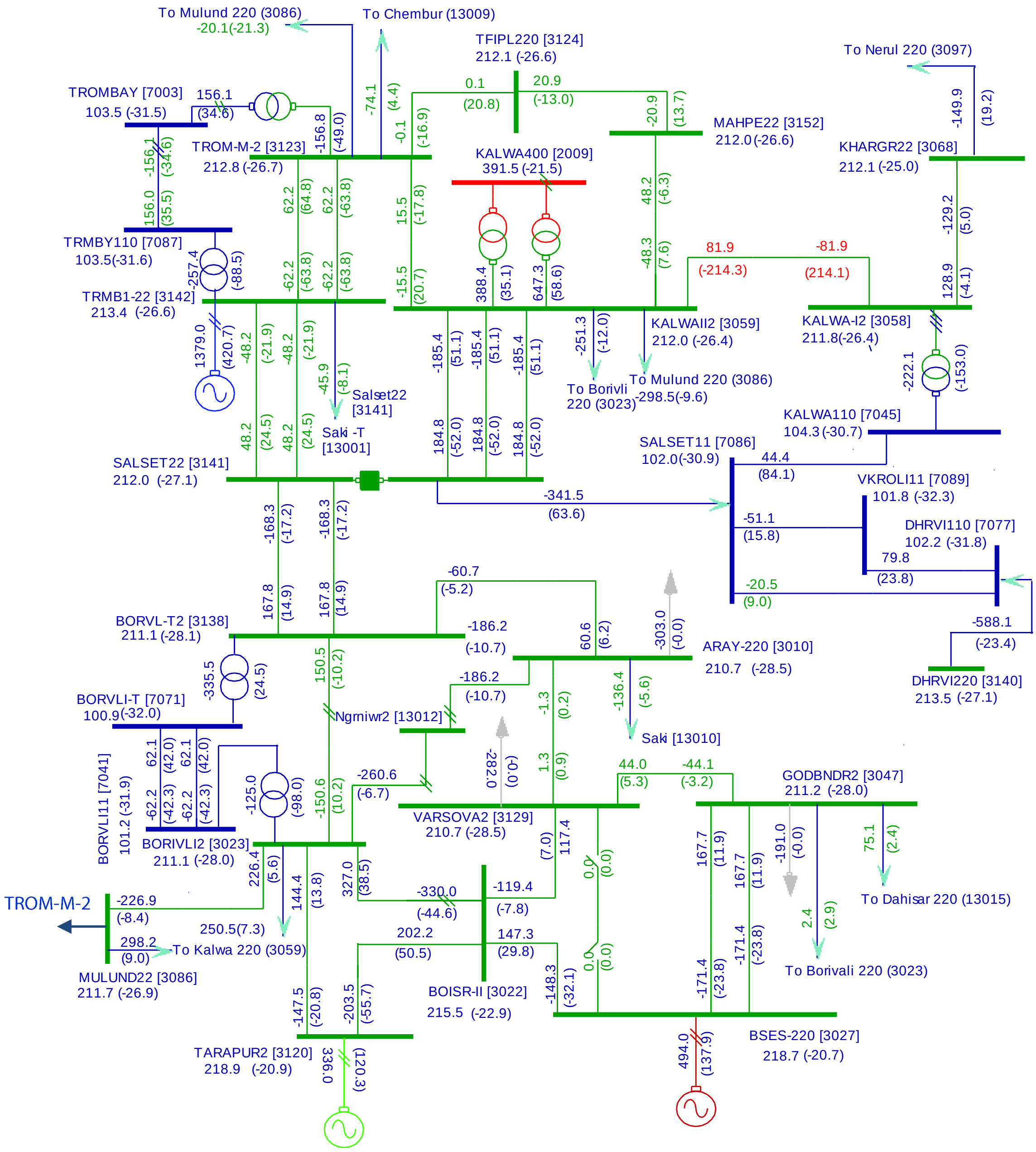

Fig. C14. Dahanu – Varsova ckt 1 out

Mumbai System Load Flow Analysis

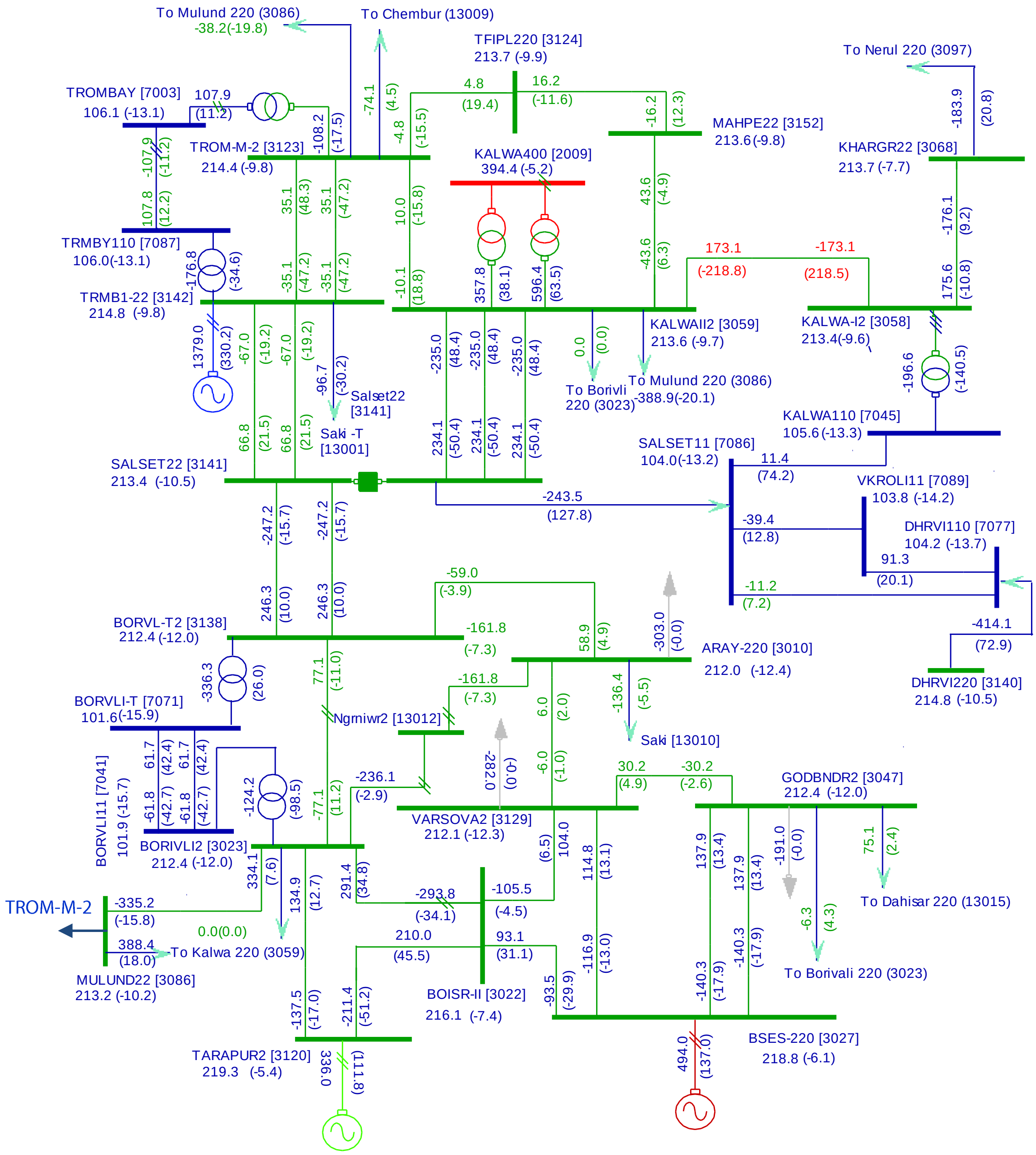

Fig. C15. Borivali – Kalwa ckt 1 out

Mumbai System Load Flow Analysis

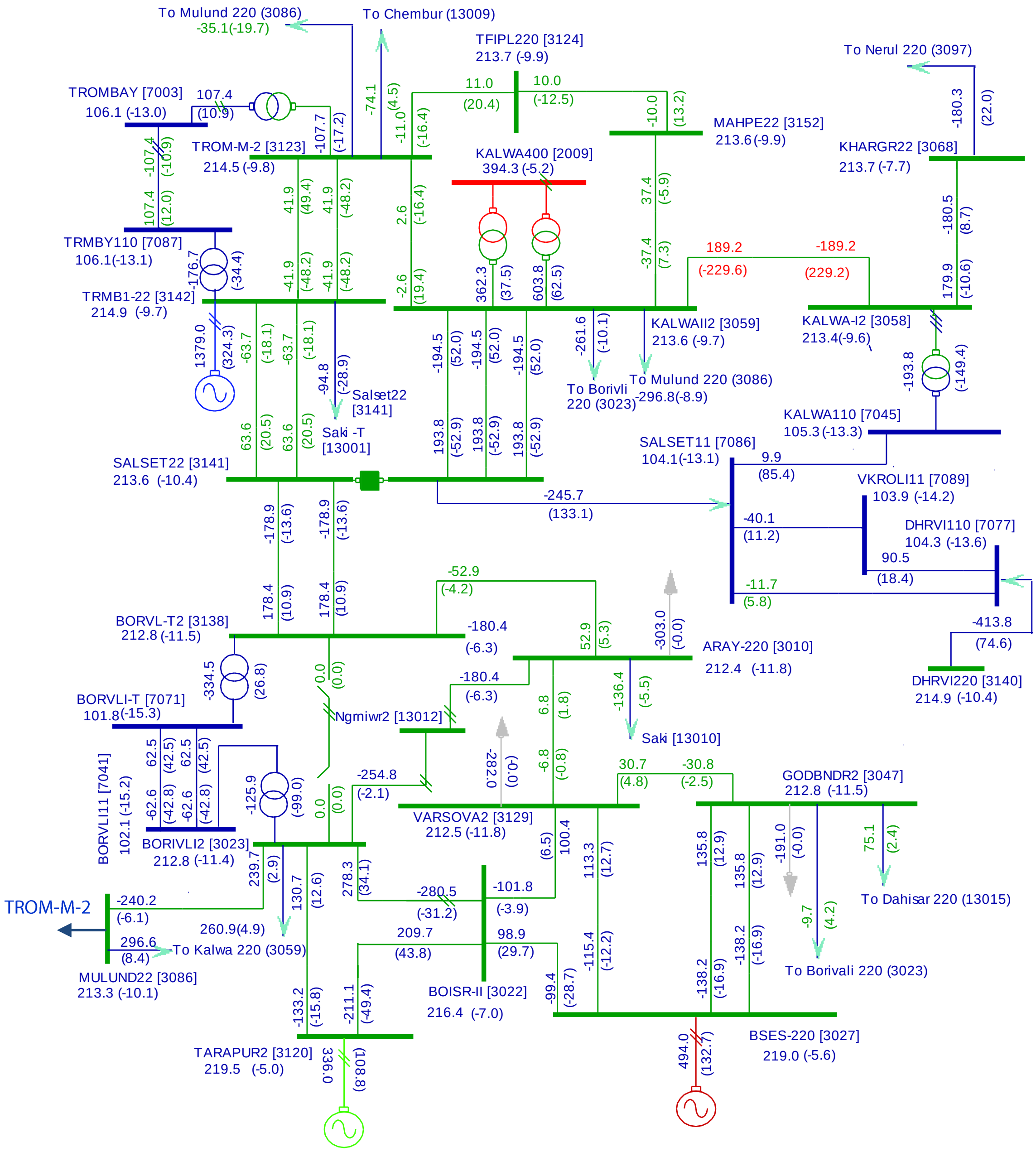

Fig. C16. Borivali – Borivali ckt 1 & 2 out