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Assessment of voltage changeability with reactive power source allotment for real time network

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Abstract. In this research work investigation of reactive power necessity at standard voltage level is practiced. The 39-bus test network modeled in mipower application is a part of Rajasthan power system, attached with North Regional National Grid synchronized at 765 kV voltage level. State power utilities are unable to obtain the profoundness in providing, static or dynamic compensation at multiple voltage available within the grid. Reactive power drawl from the network end is judged and analysed by placing imaginary generator at available voltage level. In Rajasthan power system voltage level arrays from 765 kV to 33 kV and the utilities are puzzled in managing var penetration due to poor estimation. As a result, higher loading levels and abrupt line tripping raises losses and reduces system reliability. The simulation case studies presented herby from the database of financial year 2018-19 will be envisaged by the utilities after evaluation is over. Presently State Load Dispatch Centers deliver instruction to substations to utilize any compensation device available without prior calculation. But this paper underlines a way to access the effects on voltage profile, losses etc. in power system structure after planned var support at optimum voltage level. Case studies over real time network is detailed, to check the observability for a load of 370 MW. The impact of practices followed is observed for the designed network.

Keywords. Voltage variations; reactive power management; inductor; capacitive assessment.

1. Introduction

With the rising demands of electricity, the load areas are enlarging yearly. As a result, emphasis is laid on providing power to consumer at their local side, since load areas have been extended far from conventional generating plants. It raises the dependency over reactive power penetration in grid. Transmission network is a complex structure, with the predictable rush in electricity demand for the future [1, 2]. All power utilities are trying their best to replace coal fuels with green energy sources, these fast integration of renewable energy in the transmission network needs essential planning sooner than later.

Engineering practices are expanding multidimensionally. Basic load flow studies are shifted to optimization along with blends of artificial intelligence, mathematical models and multi-agent-based approaches are varying the traditional pattern of grid management, present time focus is on technology available and its upgradations. As per the 13th electricity plan peak electric load will hit 19,692 MW till 2021–2022 [3, 4]. As Var requirement depends on peak loads along with power factor. The power system angles dictate the position of active flow with respect to reactive support in parallel. Good utilization of power presents less demand of var and vice versa. In developing nation power factor remains between 0.65 and 0.80. The reactive power compensation business is rolling in crores over the current financial year with an increased compound annual growth rate of 22.5 %. Sources predicted that increment in smart devices utilization essentially require inverters which may boost up the capacitor market from 394 $ million in 2017 to estimated $ 625 million by the advent of 2023.

Government through its make in India slogans is also influencing the wide uses of capacitors in local compensation at load end. Utilization of capacitors for var injection is a supportive feature for grid utilities. It provides system engineers a facility to maintain voltage of the nodes as well as it also helps in raising the power transfer capability of the network.

Rajasthan State power system area is wide, hierarchal voltage level varies from 765 kV to 33 kV, but the utilities are still unable to obtain profound voltage level suitable for static or dynamic compensation due to poor analytics [5] and load estimation, it is reflected in database of financial year 2018–2019. Research study was carried out for the role of var injection in maintaining the grid. Evaluation is carried out at multiple voltage level over the reactive power withdrawal from the source and fulfilling at the consumers

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Table 1. Test network simulation input data.

Sl. no.	Input data	No.	Data values
1	Total real power load	–	337.736 MW
2	Total reactive power load	–	253.302 MVAr
3	Load power factor	–	0.80
4	Number of generator buses	01	–
5	Total number of buses	39	–
	400 KV	02	–
	220 KV	05	–
	132 KV	16	–
	33 KV	16	–
6	Number of total lines	17	574 Crt. KM
7	Number of total transfomers	44	–
8	Number of load buses	16	–
9	Shunt reactors	01	50 MVAr
10	Shunt capacitors	15	167.93 Ar

end mixed up with local compensation via shunt capacitors [5, 7, 8]. The impact and effect of improved planning in var compensation will be determined by simulation studies in the next sections.

2. Problem formulation and objectives set

Existing system of today is approaching towards increased use of power electronics devices in every sector. Smart devices adaptation means, utilization is raised and which consist of power electronics devices interface seeking reactive power [6]. Diversion towards, continuous rising demands of var must have to be pre-planned at grid sub-station level so that loading on grid could be reduced. Before providing var penetration the level of demand must

Table 2. Transformer modelling input data.

Trans. capacity (MVA) × NO. OF UNITS	Voltage level (KV)	% Z in PU	Total losses (W)
315 × 2	400/220	0.125	1090000
160 × 3	220/132	0.115	0645000
100 × 6	220/132	0.115	1530000
50 × 10	132/33	0.100	1550000
25 × 23	132/33	0.100	1909000
Total transformer losses			6724000

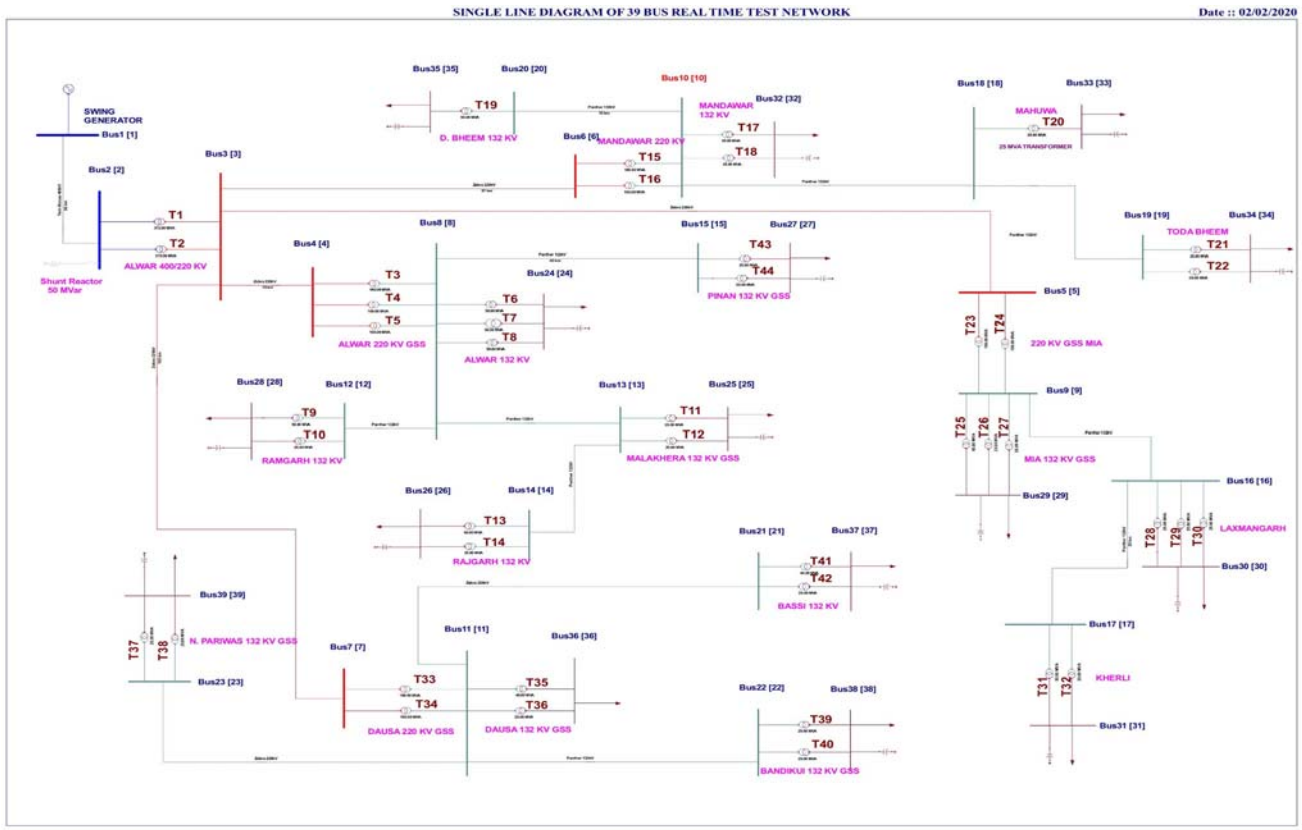


Fig. 1. Single line diagram of test network modeled in mipower.

be accurately judged for each voltage level. Because distribution companies are planning to raise dynamic var compensation at extra high voltage level which may probably reduce the share of static var compensation at lower voltages. Such situation is deeply observed here over the real time network with thirty-nine buses. Real time requirements of system at the source side is identified. Practices are performed to target the following objectives:

1. To prepare an electrical simulation model of selected thirty-nine buses of north regional belt.
2. Determining test network load and power flow situations.
3. To provide a feasible report of VAR submission dynamically at higher voltage level verses proposal of var banks at load end side.

Electrical simulation model analysed to observe the variability in network compensation at different voltage level and its effect on system is observed. The renewable penetration in Rajasthan Power System would be 66 % up to FY 2021–2022 (as per sanctioned projects than) from present value of 44 % that needs to be balanced with the presence/absence of var levels of grid. Because large variability is there with day and night sessions, at that time voltage controlling devices needs considerations [9–12].

3. Modelling of test network

Real time test network considered here is a part of Rajasthan Grid with an active load of 337 MW. Test network initializes with swing generator (Bus-1) placed at 400 KV voltage level. It is connecting 220 kV grid substations of Alwar (Bus-4), MIA (Bus-5) Mandawar (Bus-6) and Dausa (Bus-7) regions. These substations further supply power to respective sixteen number of 132 kV GSS stepped down to 33 kV voltage level. Raw data detailing its database is provided in table 1.

Test system is design via MiPower software maintain by PRDC Pvt. Ltd., Bangalore. Load is mounted at 33 kV voltage buses. Transmission lines up to 132 kV voltage level are drawn with transformers stepping down to 33 kV radial network is shown. Test network of identified area is analyzed via power map along with data collection used for test network designs. Actual power flows of network is recreated practically by simulations work of maintaining

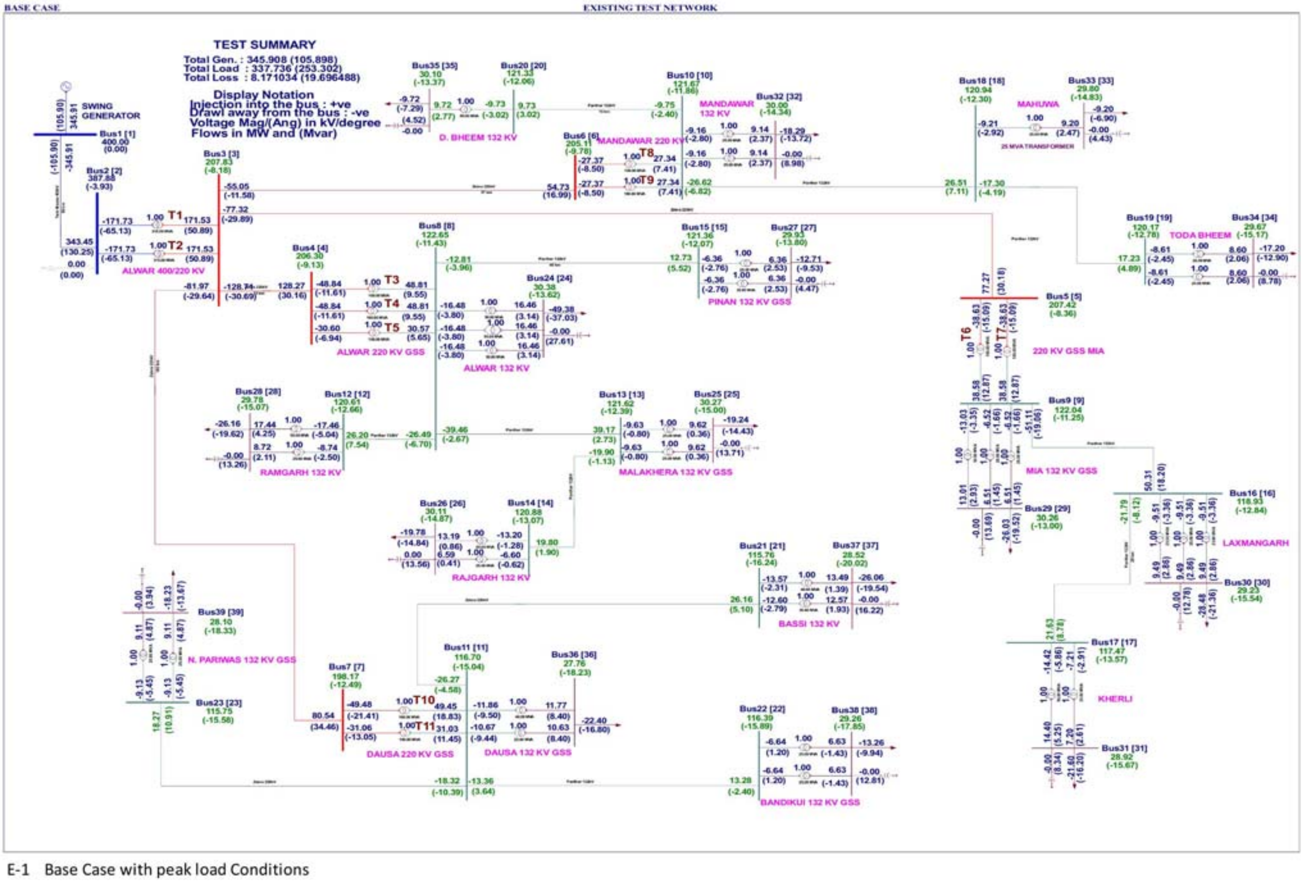


Fig. 2. Base case load flow results with peak load.

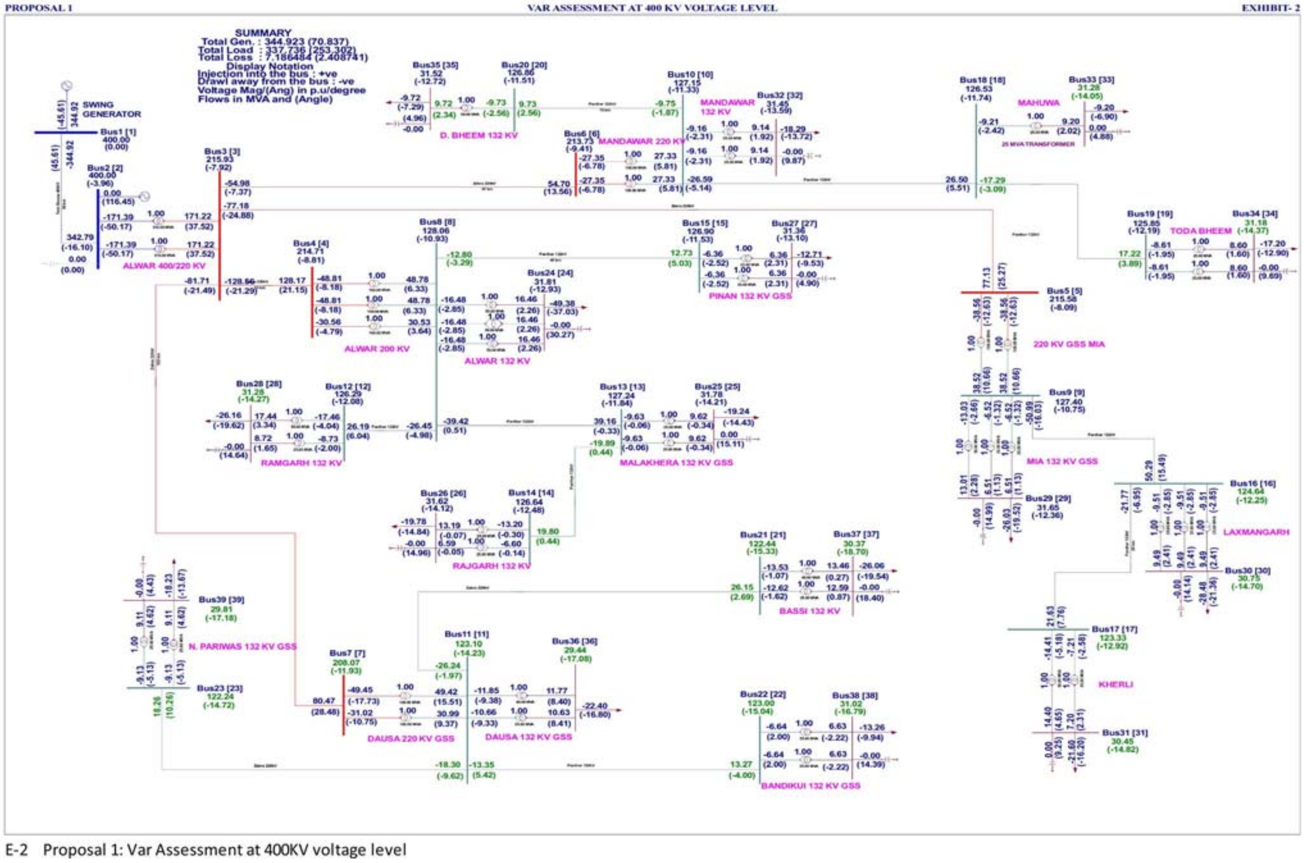


Fig. 3. Proposal 1 Var assessment at 400KV voltage level.

tap ratios, etc. Designed network simulator has 39 buses including 1 generator bus, 17 transmission lines, 16 load buses, 1 shunt reactors, and 15 shunt capacitors at 33 KV voltage level respectively.

Load is mounted at 33 kV bus network. Total system load in simulation model is 337 MW & 253 MVAR with 0.80 as load power factor. Transformer modelled is of table 2 type. The modeling of test network is shaped in software by serving all entities needed for running of all power system elements exactly mounted along with (even individual component losses are too injected) the designed libraries of components calculated and placed in simulator [13–16].

Data was collected and system was modeled. Single line diagram is briefed in figure 1.

The upcoming sections are dedicated to simulation study of test network by determining load flow values of existing power system network working in real time.

4. Simulation case studies

The research work contributes toward case study of existing problems in test belt of Rajasthan Power Network. Actual requirements of var compensation are not judged actually and during peak times losses of test network raises. Also, during low peak load time when transmission network generates higher var. Capacitors should be made off and reactors must attach as On situation. Generally, utilities are trying to provide high amount of dynamic var compensation on higher voltages but they must have to be aware of needs and necessity of actual var in the complete system. Multiple voltage levels are there and therefore real time needs vary from situations to seasons. There might be a possibility that if compensation provided at suppose 400 kV is provided but it will majorly relief the busses and sections in proximity to that identified voltage level. What will be the situation if it is not able to pass on the var addition to lower bus network that is if in surplus demand of var, due to nearby load packets [17–20]. So, these studies are carried out here by multiple case studies. Generally, two condition arises the first is peak load and the other is off-peak load.

The under and over saturation of the grid elements during any season or at any situation over reactive power variance must be looked out. Two types of divisions are studied hereby one with a peak load condition of 337 MW and the other with fifty percent reduced load of 168.86 MW similar to situation existing today, test network will be accessed. Studies with peak load conditions are analysed in four different patterns comparative to base case which is the existing one.

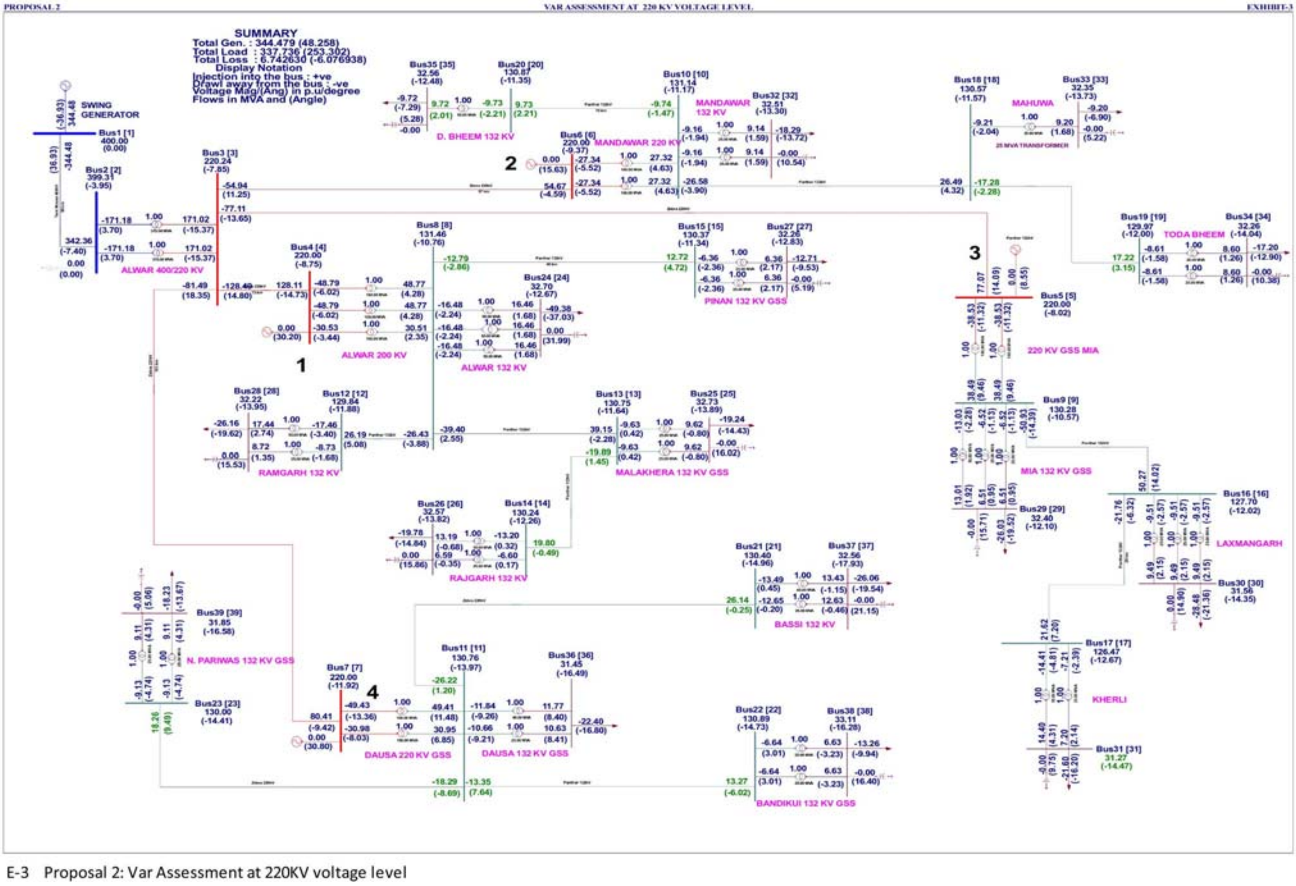


Fig. 4. Proposal 2 Var assessment at 220KV voltage level.

E-1 Base Case with peak load Conditions
E-2 Proposal 1: Var Assessment at 400KV voltage level
E-3 Proposal 2: Var Assessment at 220KV voltage level
E-4 Proposal 3: Var Assessment at 132KV voltage level
E-5 Proposal 4: Var Assessment at 33KV voltage level

In this network var compensation of 167 MVAr capacity is injected by shunt capacitors made available at load end while shunt reactor of 50 MVAr is also installed already. Load flow studies using newton Raphson method is carried out and results are detailed in figure 2.

Base case study briefs that in meeting peak load conditions the active and reactive losses of 8.17 MW, 19.69 MVAr occurs. Amount of 105.90 MVAr as var injection is provided by swing generator, transported to the consumers.

Now simulation is performed to check the network VAR demand by placing imaginary VAR Generator in proportional to net system load. Because demand will be as per the load attached. Hence studies are initiated with imaginary Generator 2 placed at 400 KV level, Bus 2 to check thenet work demand in respective area shown in figure 3.

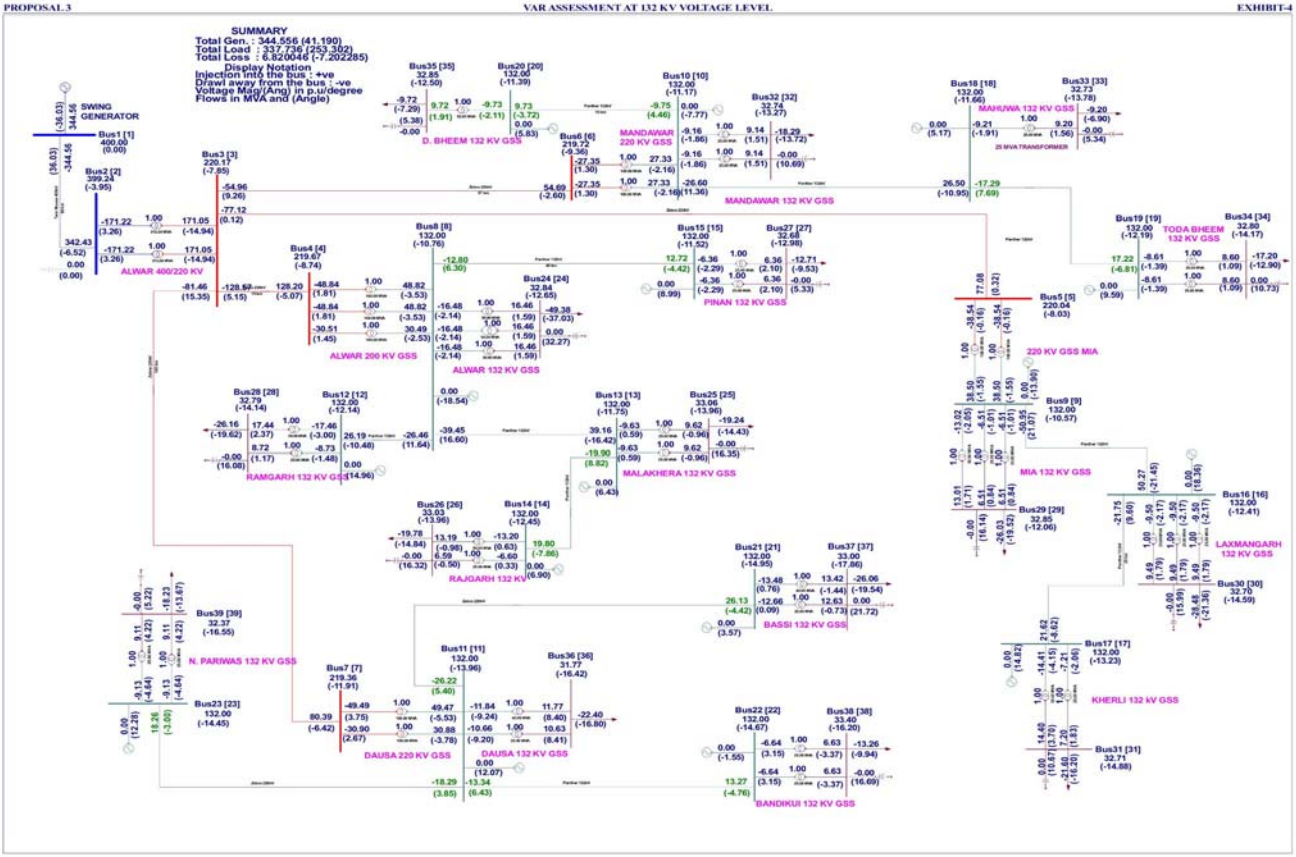
It is observed that 116.45 MW amount of var is the desired compensation required at this section of network. Which could be made available by installing large size dynamic var compensation units. Exercise similar to 400 KV is repeated in Proposal 2 where four number of 220 kV Sub-stations are provided with imaginary generators of 75 MVA capacity each. Load flow results at 220 KV buses are detailed in figure 4 above. The demand of var is fulfilled by placed VAr generators. Analytics at 220 KV shows high capacitive and less inductive demand, will be discussed ahead.

Next Proposal 3 is taken in figure 5 where compensation callat 132 KV is identified. Data is recorded for analysis.

The final proposal 4 is also simulated and fictious var generators at 33 kV are provided. Individual losses and voltage profile are detailed in figure 6 could be seen.

The peak load analysis with assessment of reactive power at 400,220,132 and 33 kV voltage level are simulated and recorded over losses, voltage profile and effects over swing bus. Also, another condition where load is reduced to fifty percent of existing is fixed to observe the change in nature of reactive power requirements with respect to voltage profile.

E-6 Base Case with off peak load Conditions
E-7 Proposal 1A: Var Assessment at 400KV voltage level
E-8 Proposal 2A: Var Assessment at 220KV voltage level



E-4 Proposal 3: Var Assessment at 132KV voltage level

Fig. 5. Proposal 3 Var assessment at 132 KV voltage level.

E-9 Proposal 3A: Var Assessment at 132KV voltage level
E-10 Proposal 4A: Var Assessment at 33KV voltage level

In off peak conditions the system capacitor banks are discontinued and reactor already installed is switched ON as per the need of time.

5. Test network outcome analysis

Incremental losses in network and poor voltage profiles reduces system reliability to a large extent at present. Available bus voltages after load flow study for base case is plotted in figure 7. It depicts the depleting voltage profile of the existing test network which could be improved by the practices suggested in the paper.

5.1 *Impact on voltage profile*

The demand of active and reactive power changes with voltage level. As the reflection of load demand or location of source varies the requirements of active and reactive power varies. Utilities are unaware of the action strategy that how to maintain compatibility between system elements installed at different voltage level. Basically, voltage profile of buses varies from 0.80 Pu to 1.05 but both these voltage levels boundary points are dangerous for any grid network. As they are above the planned limits sets at national and international recognition. Grid network where the profile ranges varies to ±3 % from unity or range of $0.97 \leq V \leq 1.03$ could be said as the most desirable pattern if obtained for a healthy grid network. Comparative simulation results detailing range of Bus voltages over base case & proposals is in table 3.

Inferences from table 3 shows that, not a single case of overvoltage specially above 1.05 is obtain in any proposal. Majority of buses in present scenario (peak load base case) are lying in poor voltage profile. Now when compensation at 400 KV is provided than still only 6 buses improved to better, rest scenario is still the same as a result the compensation unable to pass on to downstream. A few of them improved in next lower voltage compensation. Comparatively good results are obtained in P4 where benefit of compensation is directly transferring to buses associated with them and var compensation is directly utilized by load end consumers. Similar trend is observed for off peak load conditions where the

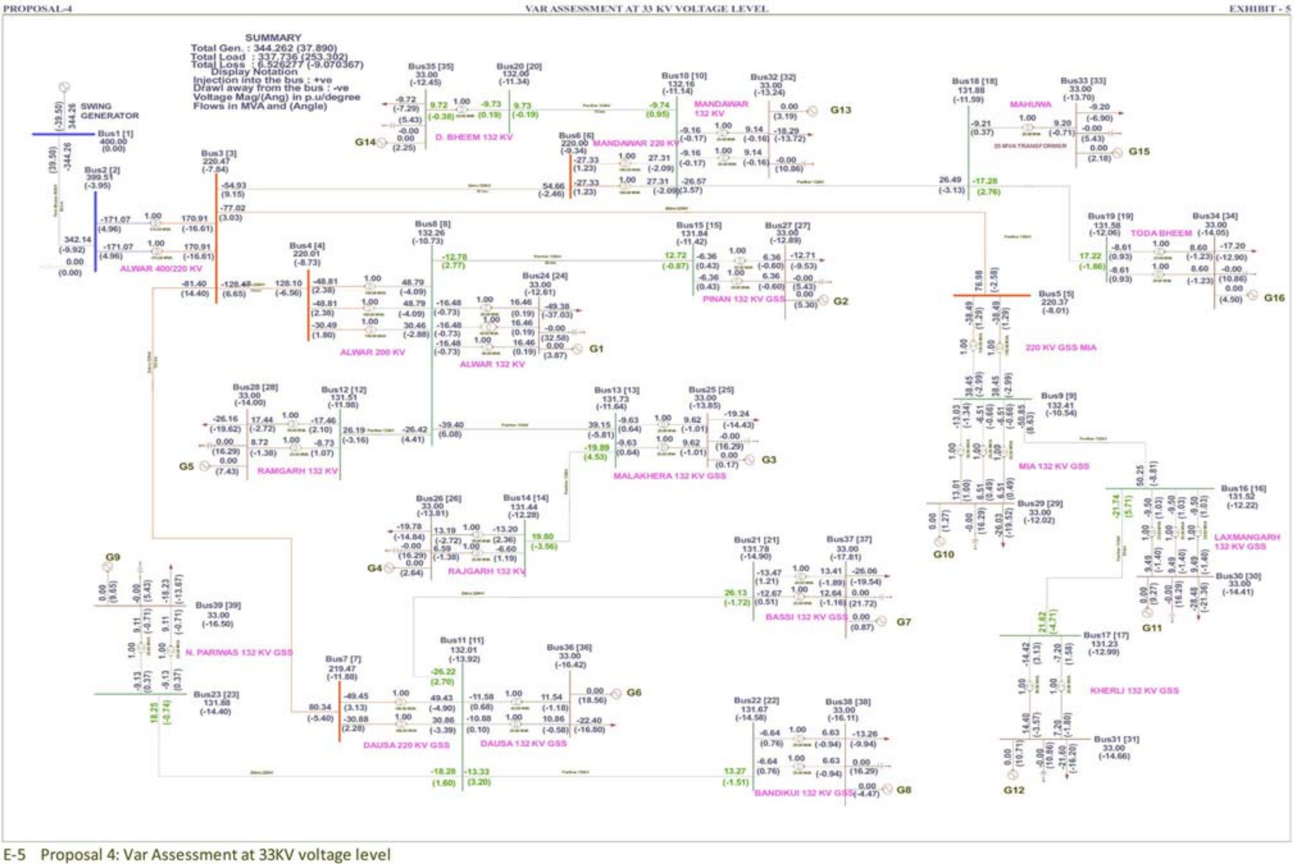


Fig. 6. Proposal 4: Var assessment at 33 KV voltage level.

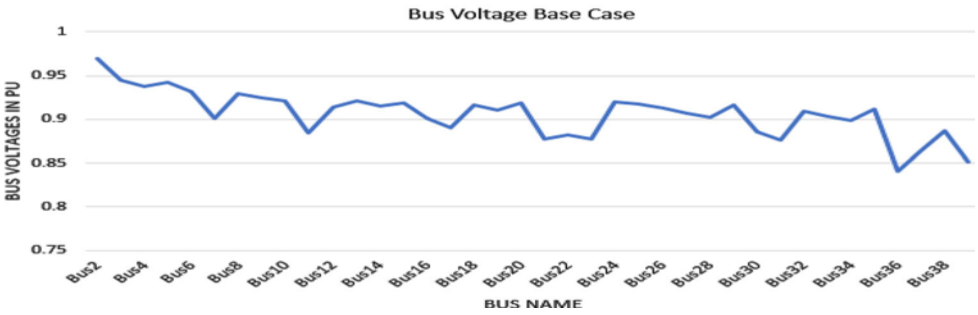


Fig. 7. Load flow results of base case.

transmission sector is capable enough to generate var due to reduced loadings. No high voltage issues are observed. But still it is observed that in proposal one six buses are below 0.97 PU even when test network is in generating mode. Graphical Comparison of proposals is give in figure 8.

Graphical results on per unit basis suggest wide variation in voltage ranges of P1, P2 as compared to existing base case. It indicates the desire of reactive content not meet at buses resulting in poor voltage profiles of buses. Profile P3 balances the voltage values but quite differences are obtained at lower distribution end buses of 33 kV level. Overall P4 profile could be called as a balanced one where streamlined type variations are observed in terms of voltage values and also the level of reactive power content is reflected as balanced one. Lastly thevoltage values in PU and volt is provided in table 4 to obtainbasic idea of values existing in field.

Table 3. Bus voltage profile.

Peak load condition buses classification					
Voltage range in PU	BC	P1	P2	P3	P4
$1.00 \leq V \leq 1.05$	01	00	02	05	09
$0.95 \leq V \leq 1.00$	01	23	36	34	30
$0.90 \leq V \leq 0.95$	25	15	01	00	00
$0.80 \leq V \leq 0.90$	12	01	00	00	00
Required and obtained range of bus operation					
$0.97 \leq V \leq 1.03$	01	07	33	38	39
Below 0.97	38	32	06	01	00
OFF peak load condition with reduced load					
Voltage range in PU	OFFBC	OFFP1	OFFP2	OFFP3	OFFP4
$1.03 \leq V \leq 1.05$	4	1	1	1	2
$0.97 \leq V \leq 1.03$	35	32	38	38	37
$0.90 \leq V \leq 0.97$	00	06	00	00	00
$0.80 \leq V \leq 0.90$	00	00	00	00	00

5.2 *Inductive/capacitive analysis and swing bus variations*

It is a known fact that supplementary power output from the generator will reduce the money invested in power purchasing from the other end. It may economize utility by selling the extra marginal power obtained just by making suitable investment in shunt capacitor banks as var elements. Existing scenario draws 105.9 MVAr from grid and when imaginary var generators are provided at 400 KV level 116.45 MVAr is capacitive demand which are high as compared to 81.86 MVAr for 33 kV network all these in peak load situations. Swing bus loading as per capacitive/inductive behaviour is detailed in table 5. If off peak load is considered then network is in generating mode and to hold 400 KV voltage at grid level var generator tries to provide higher var output valued as 220.90 MVAr in simulation result. That is too less in 33 kV case.

Overall swing bus loading is lessened, further in P4 as compared to P1 which is better than base case.

Table 4. Voltage profile range of operation.

Voltage range	Volt.1	Volt.2	Volt.3	Volt.4
1.05 PU	420	231	138.60	34.65
1.03 PU	412	226.6	135.96	33.99
1.00 PU	400	220	132.00	33.00
0.97 PU	388	213.4	128.04	32.01
0.95 PU	380	209	125.40	31.37
0.90 PU	360	198	118.80	29.70
0.80 PU	320	176	105.60	26.40

5.3 *Impact on test networks losses*

MW and MVAr losses are obtained and compared for all the cases. Results are provided in table 6. It depicts that var compensation when injected from altered voltage level than it shows variation in network losses for the same 39 Bus network. Firstly, the reduced var loading for the swing generator reflects by raising system redundancy more at 33 kV level and less at 400 KV similar trends obtained for loss pattern as in table 6.

Existing losses are reduced from 8.17 MW to 6.52 MW with one-time saving of 1.65 MW in peak load conditions. In general, literature study shows that var demand is highest at load side and as the demand is fulfilled the losses will be automatically reducedsince var overdrawing along with transportation from swing bus and mid-network will be reduced. Afterwards the generator side operator free to utilize the swing generator in making economy for the utilities instead of serving its difficulties. Lagging in voltage could be now better managed by team of capacitor banks installed. Thus, if strategy followed in proposal 4 is exercised in the system then savings could be maintained at system level. Obtaining this savings in energy unit and economic scale is detailed below. A load factor of 0.80 is taken assuming 80 % of devices in ''On'' condition for a normal load.

Annual Energy Savings of Test System

$$\begin{aligned} &Loss\ load\ factor(LLF) = 0.3(LF) + 0.7(LF)^2 \\ &(LLF) = 0.688 \end{aligned} \tag{1.1}$$

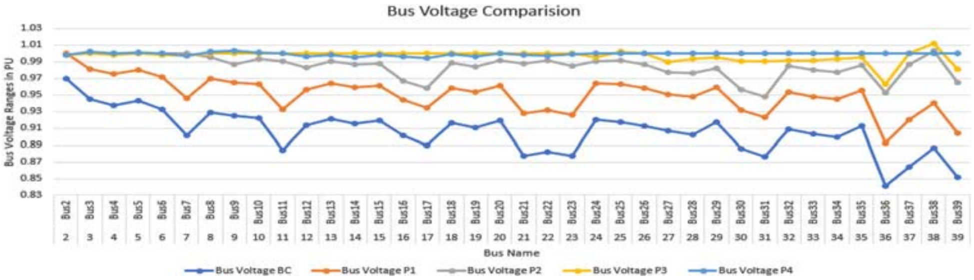


Fig. 8. Bus voltage comparison profiles of proposals advised.

Table 5. Voltage profile range in operation.

Assessment values	BC	P1	P2	P3	P4
Peak load	337.73 MW/ 253.302 MVAr				
Capacitive	Not applicable	116.45	85.19	118.98	81.86
Inductive	Not applicable	00	00	− 41.759	− 4.48
Swing gen. loading	105.9 MVar	− 45.61	− 36.93	− 36.031	− 39.495

Assessment values	BC	OP1	OP2	OP3	OP4
Off peak load	168.86 MW/126.65 MVAr				
Capacitive	Not applicable	00	8.597	71.45	6.99
Inductive	Not applicable	− 177.9	− 74.28	− 108.49	− 24.67
Swing gen. loading	29.5 MVar	220.90	101.89	70.95	49.305

Table 6. MW losses comparison of proposals.

Losses	BC	P1	P2	P3	P4	Savings
MWPEAK	8.17	7.18	6.74	6.82	6.52	1.65
MWOFF-PEAK	1.61	1.554	1.97	1.84	1.69	0.06

Losses	BC	P1	P2	P3	P4	Savings
MVARPEAK	19.7	2.40	− 6.07	− 7.20	− 9.07	–
MVAr OFF-PEAK	− 79.7	− 62.6	− 71.6	− 74.6	− 77.2	–

$$AES = [1.65 \times 8760 \times LLF/102\, LUs/Annum] \tag{1.2}$$

$$AES = 99.44\, LUs/Annum \tag{1.3}$$

Annual Cost Savings of Test System

$$Annual\ cost\ saving = Units\ Saved \times Tariff\ Rate \tag{1.4}$$

$$ACS = (99.44) \times (5) \tag{1.5}$$

$$ACS = Rs.497.21 Lakhs/year \tag{1.6}$$

The above calculations (1.1–1.6) conclude that fulfilling the var requirements at 33 kV as per the demand will have profound impact on voltage profile as compared to 400 KV level. Timely utilization of var absorbers/providers could maintain the healthy voltage range of network buses with reduced overall losses. Utilities could save an amount of Rs 497.21 LUs and energy savings of 99.44 lakh units per year.

6. Conclusion

Voltage variation in real time network is a big issue with many possible reasons. The study was carried out for North regional grid connected section.. Voltage changeability of buses with respect to inductive-capacitive variation for multiple voltages of network is considered. As future planning of utility to provide dynamic var compensation at high voltage level, the pros and cons in providing the desired var compensation at load end voltage of 33 kV (including other mid voltages) are discussed. Simulation study say that during compensation lines requirement as per voltage level must be checked out. Means load end buses are generally higher in count benefit of position is there when var injection is provided to them, easily passing on of VAr is there. As a result, network losses, requirements, voltage profile variations on system could be more balanced one and estimated too. Simulation study submits following annotations.

Requirement of reactive power reduces as utility goes from high to low voltage side i.e., towards consumer end. It causes utility to plan dynamic var at higher voltage level. Second inference says that compensation at higher voltage, raises power factor of a number of buses on higher side which is not so in case when compensation by shunt capacitor banks is provided at local end. Similarly, higher losses observed in dynamic compensation at 400 kV voltage level, while that of other case, suggesting utilities to gain money by reducing network losses to nearby 1 MW to 1.5 MW. Lastly, the level of loading at grid side is at reduced level when compensation is made at consumer side. Because it is the actual location where demand exists and compensation is made.

Thus benefiting grid equipment's to work on higher side or under higher losses. Escalation of system reliability by reducing losses, preserving voltage profile of network buses under desired range, at present could be achieved by practicing the case study carried out in this paper. Future studies could be carried out by multi agent services in identifying the actual quantum [21] of system.

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