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Central Institute for Rural Electrification
of
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Hyderabad, Andhra Pradesh, India

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BEST PRACTICES IN TECHNICAL LOSS REDUCTION

Technical Losses

- The technical losses are due to energy dissipation in the conductors and equipments used in the system for transmission and distribution of power.
- The magnitude of energy dissipation depends largely on the design of lines, pattern of loading of transmission and distribution lines, types of loads, equipments (transformers), etc.
- It is not possible to eliminate such inherent losses in a system altogether.

Technical Losses(Contd….)

This could, however, be reduced to some extent by better design of lines, re-location of distribution sub-stations, installation of capacitors, use of higher efficiency transformers, regular system upgradation etc.

TECHNICAL LOSSES- Overview

- Major amount of losses in a power system occur in primary and secondary (P&S) distribution lines i.e.,11 kV & 400V
- Losses in sub-transmission (33 or 66 kV) and Transmission lines account only about 30% of total losses
- Therefore Primary and Secondary Distribution systems must be properly planned to ensure losses within stipulated limits

High Technical Losses In Primary & Secondary(P&S) Distribution Systems-Reasons

1.Lengthy Distribution Lines:

- Primary & Secondary distribution lines are laid radially, usually over long distances. This results in high line resistance and therefore high I2R losses in the line.

2.Inadequate Size of Conductors:

1. As stated above, rural loads are usually scattered and generally fed by long radial feeders. The size of the conductor should be adequate and should be selected on the basis of KVA X KM capacity of standard conductor for a required voltage regulation.

High Technical losses in P & S Distribution Systems-Reasons(contd….)

Tables 1&2give the length of the lines for 11 kV and 415 Volts corresponding to different loads for the voltage regulation prescribed by Electricity Rules, for different sizes of conductors respectively.

High Technical losses in P&S Distribution Systems-Reasons(Contd..)

- **Table-1:Lengthof 11kV line corresponding to Different loads**

Size of conductor (with code No.)	*KVA-KM for 8% voltage drop at 0.8 PF*	*Maximum of length of line (KM)*	*Load that can be connected (KW)*
50 mm2 ACSR Rabbit	10,640	30	355
30 mm2 ACSR Weasel	7,200	20	360
20 mm2 ACSR Squirrel	5,120	15	341

High Technical losses in P&S Distribution Systems-Reasons(Contd..)

- **Table-2:Lengthof 415 Volts line corresponding to Different loads**

Size of conductor (with code No.)	*KVA-KM for 8% voltage drop at 0.8 PF*	*Maximum of length of line (KM)*	*Load that can be connected (KW)*
50 mm2 ACSR Rabbit	11.76	1.6	7.5
30 mm2 ACSR Weasel	7.86	1.0	7.86
20 mm2 ACSR Squirrel	5.58	1.0	5.58

High Technical losses in P&S Distribution Systems-Reasons(Contd..)

3.Distribution Transformers not located at load Centre on the Secondary Distribution System:

Often DTs are not located centrally with respect to consumers. Consequently ,the farthest consumers obtain an extremely low voltage even though a reasonbly good voltage level is maintained at the Transformer secondaries. This again leads to higher line losses.

High Technical losses in P&S Distribution Systems-Reasons(Contd..)

4.Over-rated Distribution Transformers and leading to under utilization:

- Sometimes Higher rating DTRs are used than required, resulting in high iron losses and higher capital costs.
- Appropriate transformer capacity with reference to load requirement isto be selected
- Standard ratings are 25,63,100,160,315 KVA

High Technical losses in P&S Distribution Systems-Reasons(Contd..)

5.Low Voltage(less than declared voltage) at Transformers and consumer terminals:

- The permissible voltage variation in respect of secondary distribution(LV) network is +6 %to-6% at consumer's terminals. For a declared 3phase voltage of 415 volts the permissible lower limit is 390 V.
- In rural areas the predominant load is agricultural pumps driven by Induction motors,which are constant power loads.

High Technical losses in P&S Distribution Systems-Reasons

- These motors draw higher currents when voltages go down, resulting in high losses in the lines(Note: Loss is proportional to the square of the current)
- Some times voltages go down to 350 V.i.e.,variation of -15% resulting in increase of losses in the line by about 32%.

High Technical losses in P&S Distribution Systems-Reasons (contd..)

- The above situation is corrected by operating an " on-toad-tap changing" in the power transformer situated at high voltage sub-stations 66/11 KV and 33/11 KV sub-stations and providing on the 11 KV feeders a combination of switched capacitors and automatic voltage regulators.
- Further the " off load tap changing" in distribution transformers is adjusted prior to the commencement of agricultural load season which is readjusted before the on-set of monsoons when the rural load is small if the off-load tap changing gear is available.

High Technical losses in P&S Distribution Systems-Reasons(Contd..)

6. Low Power Factor:

- In most of the LT distribution circuits, it is found that the PF ranges from 0.65 to 0.75. A low PF contributes towards high distribution losses. For a given load, if the PF is low, the current drawn is high consequently, the losses proportional to square of the current, will be more.
- Thus line losses owing to the poor PF can be reduced by improving the PF. This can be done by installing of shunt capacitors

High Technical losses in P&S Distribution Systems-Reasons(Contd..)

- Shunt capacitors can be connected in the following ways:

(i) Shunt capacitors are connected on the secondary side(11 KV side) of the 33/11 KV power transformers.

Table shows from the studies carried out on 11 KV lines, how the improvement of power factor results in considerable reduction of losses.

Load(KW)	PF	KVA	Current(A)	Line Loss (KW)	Remarks
300	0.7	428	38.9	27.2	Before
300	1.0	300	27.2	13.4	After

High Technical losses in P&S Distribution Systems-Reasons(Contd..)

(ii) Line losses in LT distribution lines may also be considerably reduced by installing shunt capcitors of optimum rating at vantage points as decided during load stations.

(iii) A more appropriate manner of improving this PF of the distribution system and thereby reduce the line losses is to connect capacitors across the terminals of the motors(inductive load). The extent of reduction of line loss in this manner depends mainly on the extent to which the PF of consumer is improved.

High Technical losses in P&S Distribution Systems-Reasons(Contd..)

In this case, the capacitor is connected in parallel directly to the terminals, the capacitor being switched on and off together with the equipment itself.

Many electricity supply authorities are including a clause in terms & conditions of supply making it compulsory for the consumers to provide capacitors of adequate rating for all types of installations with connected loads of 5HP and above.

By connecting the capacitors across all individual inductive loads it is observed that 10% voltage improvement 20% reduction in current and reduction of losses up to 9% can be achieved depending upon the extent of PF improvement.

High Technical losses in P&S Distribution Systems-Reasons(Contd..)

7. Bad Workmanship Resulting in poor contacts at Joints and Connections :Bad workmanship contributes significantly towards increase in distribution losses. In this context, the following points should be borne in mind.

i) Joints are a source of power loss. Therefore the number of joints should be kept to a minimum. Proper jointing techniques should be used to ensure firm connections.

High Technical losses in P&S Distribution Systems-Reasons(Contd..)

(ii) Connections to the transformer bushing-stem, drop-out fuse, isolators, LT switch etc. should be periodically inspected and proper joint ensured to avoid sparking and heating of contacts

(iii) Replacement of deteriorated wires and services should also be made timely to avoid any cause of leakage and loss of power.

LOSS REDUCTION STRATEGY

- LOAD FLOW ANALYSIS
- SHORT TERM MEASURES
- OPTIMAL INTEGRATED STRATEGY
- LONG TERM MEASURES
- ADOPTION OF INNOVATIVE TECHNOLOGIES

LOAD FLOW ANALYSIS (LFA)

<u>LOAD FLOW ANALYSIS INVOLVES:</u>

- Calculation of Voltages at every node of network
- Power Flows and losses in each section of network

Load Flow analysis is required for assessing the existing conditions of network and plan suitable measures short term and long term, to bring down the losses and provide enough cushion for future load growth.

LOAD FLOW ANALYSIS (LFA)

Present practice :

- Long hand Calculations are done using Regulation Constants derived from KVA-KM and Loss Constants derived from KVA2-Km which are approximate.
- Well Known computerized Algorithm of LFA Viz., Gauss Siedel, Newton Raphson Fast Decoupled LF are extensively used for LFA of Transmission Networks of Interconnected Operation
- Not Best Suited For Radial Networks like Sub-transmission, primary & Secondary Distribution

LOAD FLOW ANALYSIS (LFA)

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PRESENT PRACTICES(Hand Calculation)

VOLTAGE REGULATION (V.R)

- Farthest Point of Network Is Considered as Tail End
- Consequent Sections between SS and Tail End Constitute "Main Line"
- Loads on the spur lines assumed to be concentrated at the points where the spur lines tap off from the Main Line

LOAD FLOW ANALYSIS(LFA)

Present Practices (contd..)

- The Total Load incident on each section of Main Line computed and Multiplied by its Length. Product Familiarly known as"KVA-KM"
- KVA-KM of all sections added to obtain TOTAL KVA-KM of Main Line , divided by DF and multiplied by "Regulation Constant (R.C)" to obtain % Tail End Regulation of feeder

LOAD FLOW ANALYSIS(LFA)

PRESENT PRACTICES (Contd…)

LOSSES

- Product of square of load and distance for each section(including sections on spur lines) calculated
- KVA^2-KM for feeder obtained by adding

  KVA^2-KM of all sections, multiplied by "Loss Constant (L.C)" to obtain Peak Power Loss(ppl)
- Kwh loss=ppl*LLF*No.of hours in the peroid

LOAD FLOW ANALYSIS

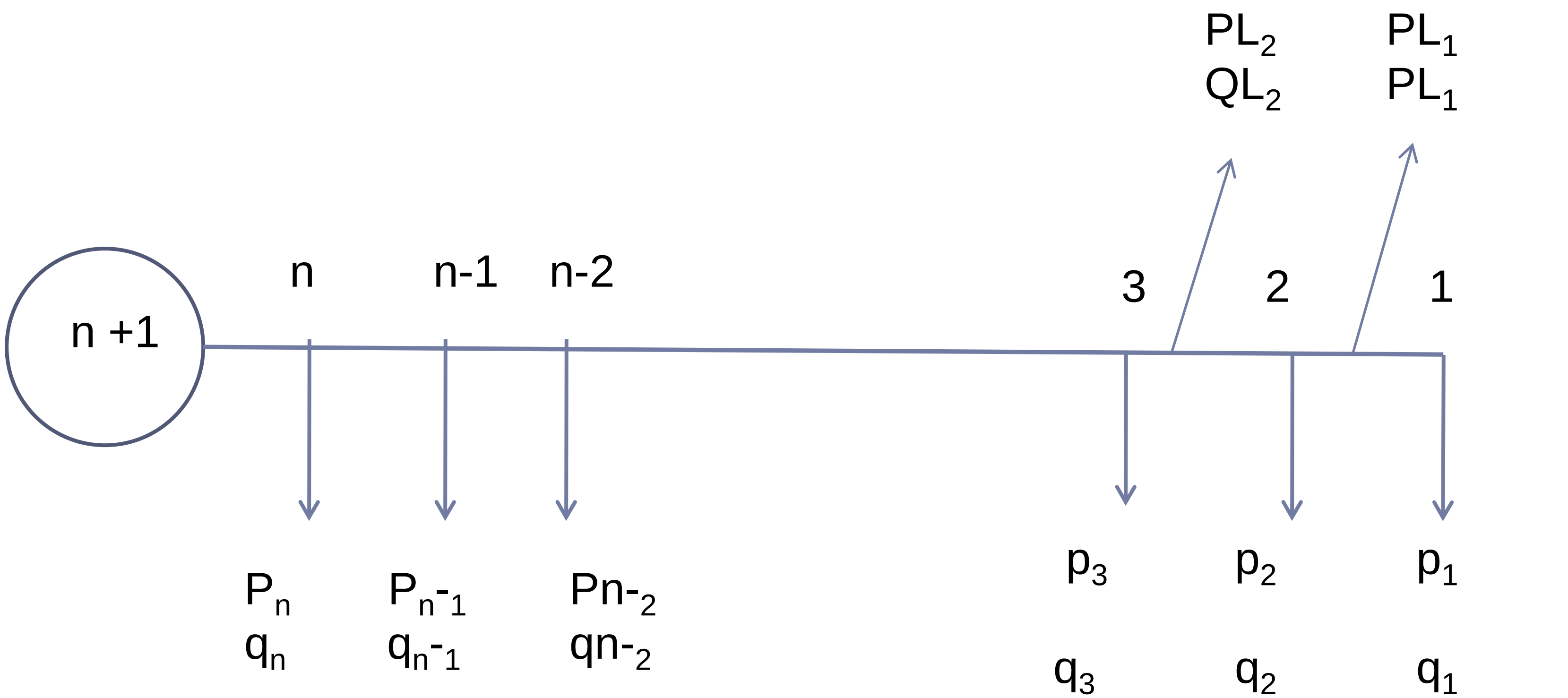
Draw Backs in the present practice:

- Calculation of VRS and losses By hand calculations using RC and LC – Time Consuming, Labourious and Approximate

- Formulae for RC and LC presume Constant Voltage at end of each section of network. Actual VR and losses will be higher.

- VR figure is for tail end. We need voltages and losses at intermediate points and on spur lines for examining the need of Boosters and Capacitors
- Assumption that farthest end of the feeder is lowest voltage point may not be true. Present Hand Calculation methods are erroneous.

RADIAL LOAD FLOW ALGORITHM (Computer Aided)



RADIAL LOAD FLOW ALGORITHM(Computer Aided)

1.Read sending end voltage E_{n+1} and active power P_i and reactive power Q_i incident on each node for i=1,n

2.Initially assume that active power loss $PLOS_i$ and reactive power loss $QLOS_i$ in each section is zero for i=1,n, Set OLD LOSS=0

3.Estimate active power(PLi)and reactive power(QL_i) flow in each section for i=1,n using

RADIAL LOAD FLOW ALGORITHM(Computer Aided)

$$PL_i = \sum P_j + \sum PLOS_j$$

$$QL_i = \sum Q_j + \sum QLOS_j$$

4.Calculate the voltage at each node starting from sending end and proceeding towards tailend

$$E^2_{i+1} = E_i^{\,2} + 2 \times (PL_i \times RL_i + QL_i \times XL_i) + (PL_i^2 + QL_i^2) RL_i / E_i^2$$

5.Calculate the active power loss and reactive power loss in each section

$$PLOS_i = (PL^2_i + QL_i^2) RL_i / E_i^2$$

$$QLOS_i = (PL_i^2 + Ql_i^2) XL_i / E_i^2$$

RADIAL LOAD FLOW ALGORITHM(Computer Aided)

6.Estimate total loss in the feeder and % of variation of the loss

$$NEWLOS= \sum PLOS_i$$

$$ERR=ABS(NEWLOS-OLDLOS)/NEWLOS$$

7.Check whether ERR is less than convergence criteria set. If Yes, Terminate the Algorithm.

RADIAL LOAD FLOW ALGORITHM(Computer Aided)

- Print active and reactive power flows and active power loss in each section and voltage at each node
- If not ,store value of latest feeder loss and repeat steps 3,4,5,6,7 till convergence limit is satisfied

LFA FOR A TYPICAL 11 kv FEEDER

- Analysis for a typical 11 kv feeder using the conventional KVA- KM method and computerized Load Flow Analysis is given for comparision .

FEEDER DATA

FEEDER NO	NAME OF FEEDER	NO.OF TRANFRMS	POWER FACTOR	LOAD FACTOR	LENGTH KM	STARTING VOLTAGE KV	DIVERSITY FACTOR	CONNECTED LOAD KW
1	kambamp adu-pedda	43	.80	.30	72.46	11.00	1.50	2453.

FEEDER ANALYSIS

FEEDER No.	NAME OF FEEDER	ACTIVE LOAD Kw	REACTIVE LOAD KVAR	POWER LOSS KW	ENERGY LOSS L.U.	% REG	% ENERGY LOSS
1	kambamp adu-pedda	2042.	1378.	406.	4.70	22.46	8.90

ANALYSIS OF NODE WISE VOLTAGES A SECTION WISE LOADING

S.No	F. Name	VOLTAGES			LOADING		
		ABOVE 94%	94.0% TO 90%	BELOW 90%	ABOVE 200%	200.0% TO 150%	BELOW 150%
1	kamb amp adu-pedda	4	4	35	9	2	38
	TOTAL	4	4	35	9	2	38

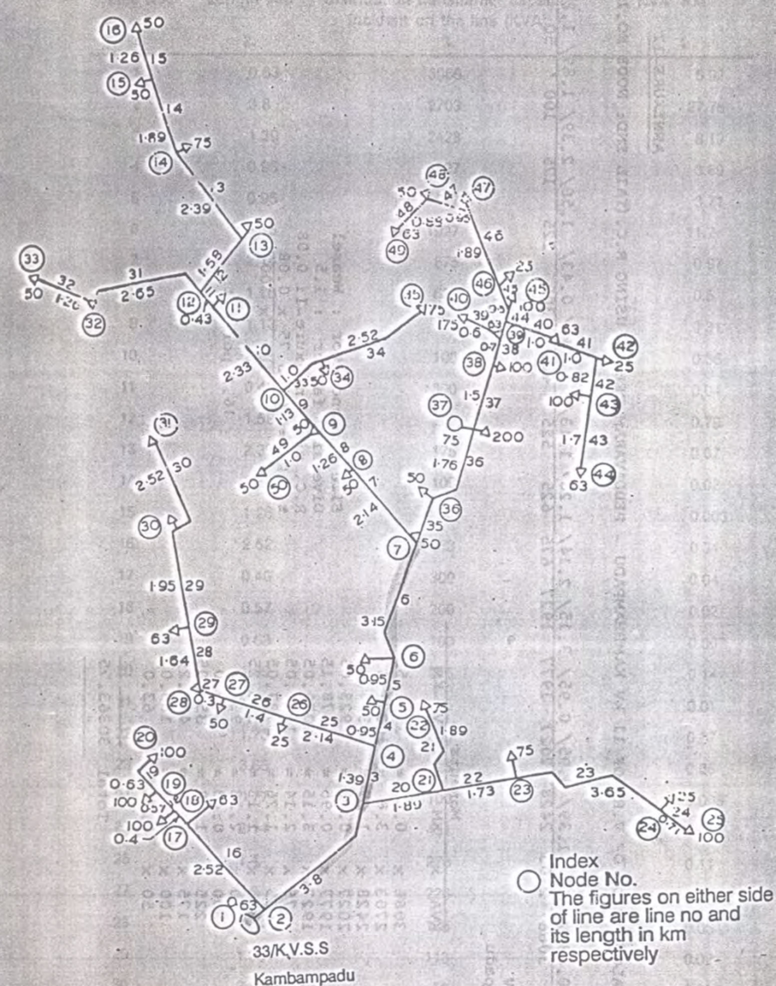


Figure 3. Layout of II K V Kambampadu - Peddavaram Feeder

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COMPARISION OF VOLTAGE AND PEAK POWER LOSS

Method	Maximum Voltage Drop %	Peak Power Loss KW
Computer Aided Load Flow	22.5	406.0
Conventional Method of Voltage Drop and Loss Constants	16.2	235.0
% Error	38.89	72.76

SHORT TERM MEASURES

- NETWORK OPTIMIZATION
  - Network Reconfiguration
  - Network Reconductoring
- VAR CONTROL
  - Shunt Capacitors

SHORT TERM MEASURES (Contd…)

- VOLTAGE CONTROL
  - Series Capacitors
  - Automatic Voltage Boosters (AVB)
- INTEGRATED OPTIMAL STRATEGY
- OPTIMAL LOCATION OF DTRS

NETWORK OPTIMIZATION

- Network Reconfiguration
- Network Reconductoring

Network Reconfiguration:

Re Routing of supply to the busses in a feeder and/or transfer & balance of loads among the feeders in the network to minimize the power losses

Network Reconfiguration (Contd..)

Network reconfiguration includes any one or all the works indicated below

- Formation of New links to minimize within a feeder to form a tree structure
- Erection of Interlinking lines to Change the area of feed from one substation to other and balance the load among the substations
- Bifurcation of existing feeder

Issues to be investigated are:

i) Identification of potential feeder segments to be considered for reconfiguration

ii) Development of a rigorous and accurate model for an improved estimation of power loss reduction due to exchange of feeder segments considering variation of voltage along the length of the feeder.

NETWORK OPTIMIZATION

NETWORK RECONDUCTORING:

- Losses can be reduced by 25 to 50% by re-conductoring first few sections (4 – 5)
- Problem of Network re-conductoring may be defined as Identification of feeder segments whose loading exceeds Break Even Loading Limits (BELL) of conductor and selection of appropriate conductor for re-conductoring which yields a return greater than minimum rate of return set (to be defined)

- Economic Load in Limit (ELL) of a conductor is defined as loading at which the total cost of the new line i.e. Cost of (Investment + Peak Power Loss + Energy Loss), over the study period considering the load growth on the feeder, is minimum
- ELL for a given conductor size is different before and after its Installation.

- Prior to installation one has a choice of conductor sizes for a given load and the size chosen affects incremental costs only
- After Installation additional expenditure has to be incurred for reconductoring which has to

be balanced against the anticipated incremental benefits

- ELL after Installation is called as Break Even Loading Limit (BELL) and is generally higher than the ELL limit before Installation

Network Reconductoring (Contd..)

- ELL and BELL values for ACSR conductors normally used in LT, 11kv & 33kv lines are given in the following table These values are derived based on :
- Assessment period of 7 years
- Load Growth of 10% during assessment period
- Peak power loss and energy loss valued at Rs 2500/kw and Rs 0.30 ps respectively
- Value of energy & power losses discounted at 10 % to arrive at present worth values

NETWORK OPTIMIZATION

NETWORK RECONDUCTORING

Typical Loading Limits of 11 KV ACSR Conductors

S. No.	Conductor Size	Area (Sqmm)	Thermal Loading (AMPS)	ELL (AMPS)	BELL (AMPS)
1	Squirrel	20	107	17	25
2	Weasel	30	139	23	34
3	Rabbit	50	193	35	69
4	Mink	60	217	41	75
5	Raccoon	80	250	49	85
6	Dog	100	300	63	102

It is sufficient when designing new networks to ask what should be done and where; but in designing the reinforcements of existing feeders an answer is needed also to the question ‘when’. Hence Network reconductoring may be considered as Time Variant Optimization Problem

VAR CONTROL

SHUNT COMPENSATION

- Load incident on distribution system is Predominantly inductive
- Shunt Capacitor supplies constant reactive power independent of load
- Optimal compensation provided for peak load condition may result in overcompensation during light load conditions,necessitating automatic switched schemes.

Shunt Compensation (Contd….)

- Problem of determining the number, size and location of Shunt Capacitors is formulated as an optimization Problem
- Objective Function is the cost of energy saved due to reduction of power losses by installation of capacitor less the annual cost of capacitors installed
- Voltage constraints need not be considered

VOLTAGE CONTROL

SERIES CAPACITOR

- Series Capacitor introduces negative reactance in the line and improves voltage which inturn also reduces the power losses
- Series capacitor can be kept in circuit during the complete load cycle without causing any adverse effect of overvoltages, during low load conditions

Series Capacitor (Contd…)

- Problem of determination of optimal location and capacity of series capacitor is formulated as an optimization problem
- Objective function is similar to that of shunt compensation
- Voltage constraint is that the voltage at the location of capacitor shall not exceed permissible upper limit

VOLTAGE CONTROL

AUTOMATIC VOLTAGE BOOSTER (AVB)

- Automatic voltage booster(AVB) is essentially an auto transformer consisting of a primary or exciting winding connected in parallel with the circuit and a secondary or series winding connected in series with the circuit. Taps of series winding are connected to an automatic tap changing mechanism

AUTOMATIC VOLTAGE BOOSTER

- AVB boosts the voltage at its point of location in discrete steps which in turn improves voltage profile and reduces the losses in the sections beyond its point of location towards receiving end
- AVBs have generally a total voltage boost of 10% in four equal steps.
- Loss reduction is directly proportional to voltage boost

AUTOMATIC VOLTAGE BOOSTER

Maximum permissible voltage boost is limitedby the difference between the permissible maximum voltage and voltage at the point of location of AVB

- Problem of determination of location and % of boost of AVB is formulated as an optimisation problem

AUTOMATIC VOLTAGE BOOSTER

- Objective function is the cost of energy saved due to reduction of losses by installation of

  AVB less the annual cost of AVB
- Desirable constraints are that the voltages at all sections should not exceed the statutory upper and lower limits
- An iterative type algorithm is adopted in the proposed solution approach

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Optimal Integrated Strategy for Reduction of Loses

- Reconfiguration among feeders is effective only if there is unequal loading among the feeders of the network. Re configuration within the feeder is dependent upon the structure of feeder. The Network Reconfiguration is cost effective, as the rate of return is high. It should be the first choice, as it improves the utility of other short-term measures
- Shunt compensation reduces losses the extent of% to %, if the power factor is low(lower than 0.8). It also reduces the loading on feeder sections and thus may avoid reconductoring. The voltage improvement due to shunt compensation is marginal except in case of very heavily

Optimal Integrated Strategy for Reduction of Loses (contd..)

- Loaded feeders. Shunt compensation alone cannot correct voltage drop
- Reconductoring of feeders reduces both losses and voltage drop when the initial sections of feeders are loaded beyond economic or break even loading limits. The existing supports generally have no strength to carry heavier conductor size and may need reelection of feeders or insertion of intermediate supports. This measure may cause some difficulties in implementation in practice.

Optimal Integrated Strategy for Reduction of Loses (contd..)

- AVB reduces the voltage drop by 10% and is very effective tool to solve voltage drop problem. The reduction of losses due to installation of AVB is marginal and as such rate is poor
- Series capacitor performance is like AVB with regard to LRVI problem.

Rule Based Optimal Integrated Strategy

Rule 1: Check the loading on the feeders in the network. If the feeders are unequally loaded viz., some feeders are heavily loaded compared to others, then reconfigure the network for minimal losses. Otherwise, go to Rule-2. The above measure automatically equalizes the loading on the feeders. Then check for losses and voltage drop. If the target values for any feeder are not achieved, go to Rule-2.

Optimal Integrated Strategy (Contd..)

Rule 2: Check the power factor of the feeders. If is below 0.95, determine the optimal number, location and capacity of the shunt capacitor banks to be placed on the network. Otherwise go to Rule-3. Check losses and voltage drop and if violated go to Rule-3.

Optimal Integrated Strategy (Contd..)

Rule 3: Check violation of which target is comparatively severe. If voltage drop violation is severe and losses are violated marginally, then install AVB on the feeders to improve voltage profile and maximise reduction of losses. If loss violation is severe and violation of voltage drop is marginal or severe, proceed for implementation of optimal reconductoring of the network.

OPTIMAL LOCATION OF DTRs

ADVANTAGES

- Reduction of peak load and energy losses in the distribution
- Improvement of voltage to the tail end consumers
- Reduction in load demand on DTR
- Overloading of conductors and Overheating of joints avoided

LONG TERM MEASURES

- LOAD FORECAST
- LOCATION OF NEW SUBSTATIONS
- ADOPTION OF HIGH VOLTAGE DISTRIBUTION SYSTEM
- STANDARDIZATION OF CONSTRUCTION PRACTICES AND O&M PROCEDURES
- DEMAND SIDE MANAGEMENT & ENERGY CONSERVATION

ADOPTION OF INNOVATIVE TECHNOLOGIES

- Use of Electronic meters with remote metering system, prepayment meters etc.,
- Extensive Use of ALL ALUMINIUM ALLOY CONDUCTORS (AAAC), AIR BUNCHED CABLES (ABC) etc.,
- RING MAIN UNITS, AUTOMATIC SECTIONALIZERS, AUTO RECLOSURES, LOAD BREAK Switches
- DISTRIBUTION A UTOMATION & SCADA
- MANAGEMENT INFORMATION SYSTEMS
- CUSTOMER RELATION MANAGEMENT

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