VOLTAGE REGULATION RADIAL DISTRIBUTING NETWORK SYSTEM IN MANAGEMENT AND PLANNING DISTRIBUTING NETWORK PROCESSES

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SUMMARY

Existing for that purpose developed “Voltage regulation radial distributing network system” - Strezoski V, Janjic D (1) is used in paper.
Radial three voltage level electric distributing network has considered by using representative model – suburb transformer’s 110/21 kV network in Vojvodina. The aim is whole customers damage minimisation in one year period that they suffer because of voltage deviation from nominal value u_n = 400 V in connection place. Such of aim mean two tasks: a) exploitation problem of voltage regulation solving – optimal under load engaging transformer’s regulation – transformers 110/21 kV and in voltage-less condition – transformers 20/0,42 kV; b) network planning process criteria widening. Load diagram in one year is considered by using load during diagram. Calculation has done while transformer’s 110/21 kV average relative load is 20 and 60 % (in a beginning and the end of exploataton time).

Voltage regulator’s position in transformers 20/0,42 kV, unic in whole period of time, are determined. Source voltage dependence on source current is determined too - transformer 110/21 kV secondary voltage u_0 depends on corresponding secondary current i_0 - “regulating function” $u_0 = f (i_0)$.
Criteria widening and corresponding measures propose in a distributing network planning processes, from reducing the whole customers damage that they suffer view point, are given in conclusion.

INTRODUCTION

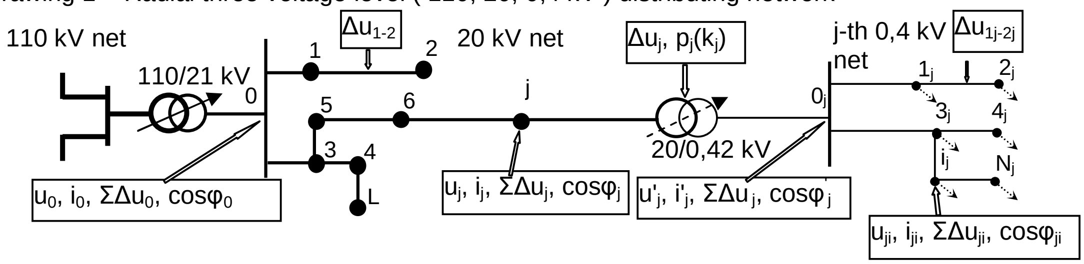
Voltage regulation in management and distributing network planning is considering because of voltage keeping in every point and every moment in permited borders +/- 10 % and the near to rated - nominal value. That reduces elementary electrical device damage because of voltage deviation. Damage depends on electrical device type, and is proportional to voltage deviation from nominal value in percents square and bought electrical energy amount. Voltage equal advisable - recommended value u_r (100 %) gives minimal – zero damage while voltage is higher or lower than recommended value damage increases:

$$D_e = C * (u-u_r)^2 * E,$$

C – damage factor, $u-u_r$ – customer voltage deviation, E – customer energy (kWh)
Recommended voltage in any point of distributing network is the voltage which causes minamal damage (D_e), that whole electrical device - equipment directly or indirectly supplied from that point suffer because of their voltage deviation from nominal value.

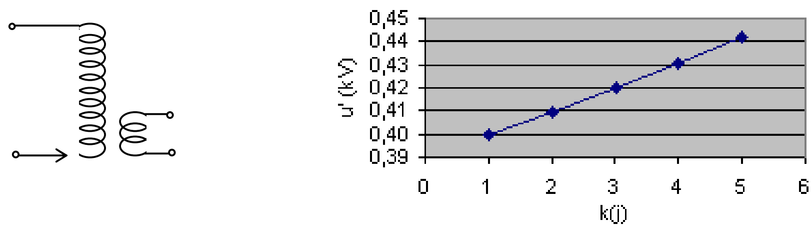
DISTRIBUTING NETWORK DESCRIPTION

Drawing 1 – Radial three voltage level (110, 20, 0,4 kV) distributing network



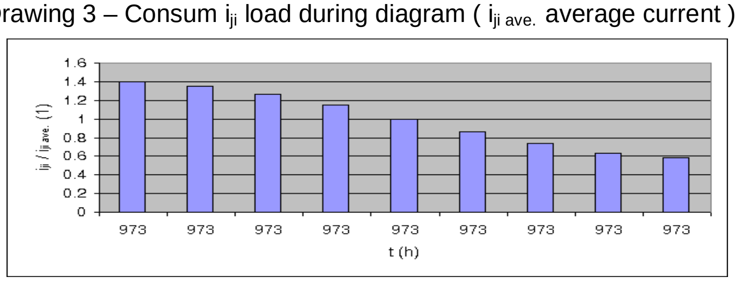
Δu_{1-2} – branch voltage sag 1-2, $\Sigma\Delta u_j$ – node voltage sag ($\Sigma\Delta u_j = \Delta u_{0-3}+\Delta u_{3-5}+\Delta u_{5-6}+\Delta u_{6-j}$, $u_j = u_0 - \Sigma\Delta u_j$), $p_j(k_j)$ – transformer voltage support - "transformer tapping boost"

Basic distributing network voltage regulation resource: two kinds of regulating transformer.
1. under load transformer regulation in real time with voltage relation continual changing 23 positions, 1,5 % step, regulating volume $\pm$ 16,0 %, 110 $\pm$ 11*1,5 %/21 kV, and
2. voltage-less condition regulation out off real time with voltage relation discret change 5 positions k(j) 2,5 % step, regulating volume $\pm$ 5,0 %, 20 $\pm$ 2*2,5 %/0,42 kV (Drawing 2).
Drawing 2 – Transformer 20/0,42 kV tapping boost realisation



p(1) = ((400 V – 400 V) / 400 V) * 100 = 0 %, p(2) = ((410 V – 400 V) / 400 V) * 100 = 2,5 %, p(3) = ((420 V – 400 V) / 400 V) * 100 = 5 %, p(4) = ((430 V – 400 V) / 400 V) * 100 = 7,5 % p(5) = ((440 V – 400 V) / 400 V) * 100 = 10 %. Transformer 20 $\pm$ 2*2,5 %/0,42 kV tapping boost is always positive, while transformer 110 $\pm$ 11*1,5 %/21 kV tapping boost is positive and negative (p(1/+11/):-10%, p(8/+4/): -1%, p(9/+3/): +0.5%, p(12/0/): +5%, p(23/-11/):+26 %).

Suppositions.
Customer recommended voltage is 102 %, in 0,4 kV instalation comsumer voltage sag is 2 %.
Every customer, line and transformer load during diagram has the same shape (in one year time).
Drawing 3 – Consum i_{ji} load during diagram ($i_{ji\ ave.}$ average current)



Distributing many voltage level network voltage sag normalisation and calculation.
During distributing network voltage sag calculation voltage change in transformer causes difficults. Because of that in (Strezoski V, Janjic D (1)) is developed "special unit relative system" distributing network calculation suitable which has characteristics: normalisated voltage values and voltage sag are equal percent value in ralation with nominal value corresponding network (no transformer's!); 20 kV network normalisated current values are equal origine values in amperes (A); 20/0,42 kV transformer are presented with transformer tapping boost (%) - than transformer tapping boost values can add to or substract from transformer or line voltage sag directly; transformer 20/0,42 kV primary current normalisated value is equal consum's 0,4 kV normalisated current sum. Consequently, two

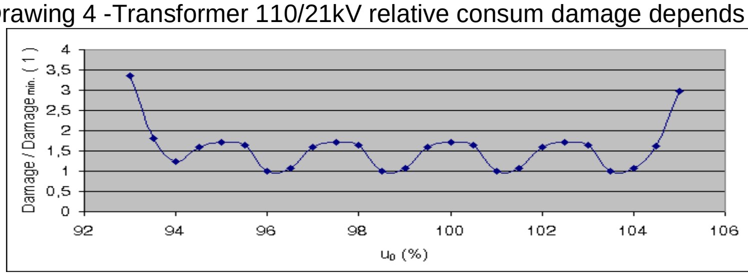
different voltage level nodes voltage modul difference is calculating by addition whole line and transformer voltage sag vith sign of addition and transformer tapping boost vith sign of substraction. $\Sigma\Sigma\Delta u_i = (\Sigma\Delta u)^i - (\Sigma p)^i$. (Drawing 1: $\Sigma\Sigma\Delta u_{ji} = u_0 - u_{ji} = \Delta u_{0\text{-}3} + \Delta u_{3\text{-}5} + \Delta u_{5\text{-}6} + \Delta u_{6\text{-}j} - p(j) + \Delta u_{0j\text{-}3j} + \Delta u_{3j\text{-}ij}$)
Electrical device (ji) damage because of voltage deviation from nominal value is:

$$D_e = f_1 (u_{ji}) = f_2 (u_0, \Sigma\Sigma\Delta u_{ji}) = f_3 (u_0, \Sigma\Delta u_{ji}, \Sigma p_j) = f_4 (u_0, Z_m, i_{ji}, \Sigma p_j)$$

Network impedances and consum currents are, from voltage optimisation view point, not variable and damage depends on 20 kV source voltage (u_0) and transformer 20/0,42 kV tapping boost (p_j) only.

OPTIMISATION PROBLEM OF VOLTAGE REGULATION

Radial distributing network voltage regulation is oprimisation problem with limits and discrete (p_j) and continual (u_0) variables. For this purpose is developed “Voltage regulation system” (Strezoski V, Janjic D (1)) where is asked “Distributing network optimal voltage regulation basic task”: “For known topologic structure and load of distributing network in choosen period of time is to: 1- in a begining of period of time calculate all transformer 20/0,42 kV tapping boosts (p(j)), unic for whole period of time and 2- calculate 20 kV network source voltage for actual load “regulating function” ($u_0 = f (i_0)$). That choice is to customers damage minimisation in one year period that they suffer because of voltage deviation from nominal value ($u_{ji} - u_r$) while keeping voltage in every point of 20 kV and 0,4 kV network and in every moment in permited borders +/- 10 %”.
Logical totality and solving algorithm are presented in (Strezoski V, Janjic D (1)). Shortly: a) recommended voltage $u_j^{'r}$ calculation for every 0,4 kV network; b) recommended primary voltage $u_j^r(k_j)$ calculation for every transformer 20/0,42 kV while suppose any initial transformer tapping boost value $p_j(k_j)$; c) 20 kV network source recommended voltage series u_0^r calculation for every load in network (series has 9 values - Drawing 3); d) arbitrary maximal voltage value choice (which corresponde to maximal load); e) optimal transformer 20/0,42 kV tapping boost calculation that in every single transformer 20/0,42 kV consum damage in whole time period is minimal; f) 20 kV network source recommended voltage series u_0^r calculation again for every load in network (series has 9 values) by using new values of transformer tapping boost; g) maximal voltage value vary while calculating whole transformer 110/21 kV consum damage in whole period of time is minimal. It is noticed, by changing maximal voltage value after every 2,5 %, necessary change every transformer tapping boost in one step – if source voltage increasing at 2,5 % all transformer tapping boosts are reduce at one step (-2,5 %) and opposite - transformer tapping boost are in “accordance”. Choosing values in optimisation are to give minimal damage and optimal transformer 20/0,42 kV tapping boost structure – regulation positions 1 and 5 engaging minimisation.
Drawing 4 -Transformer 110/21kV relative consum damage depends on 20kV network source voltage

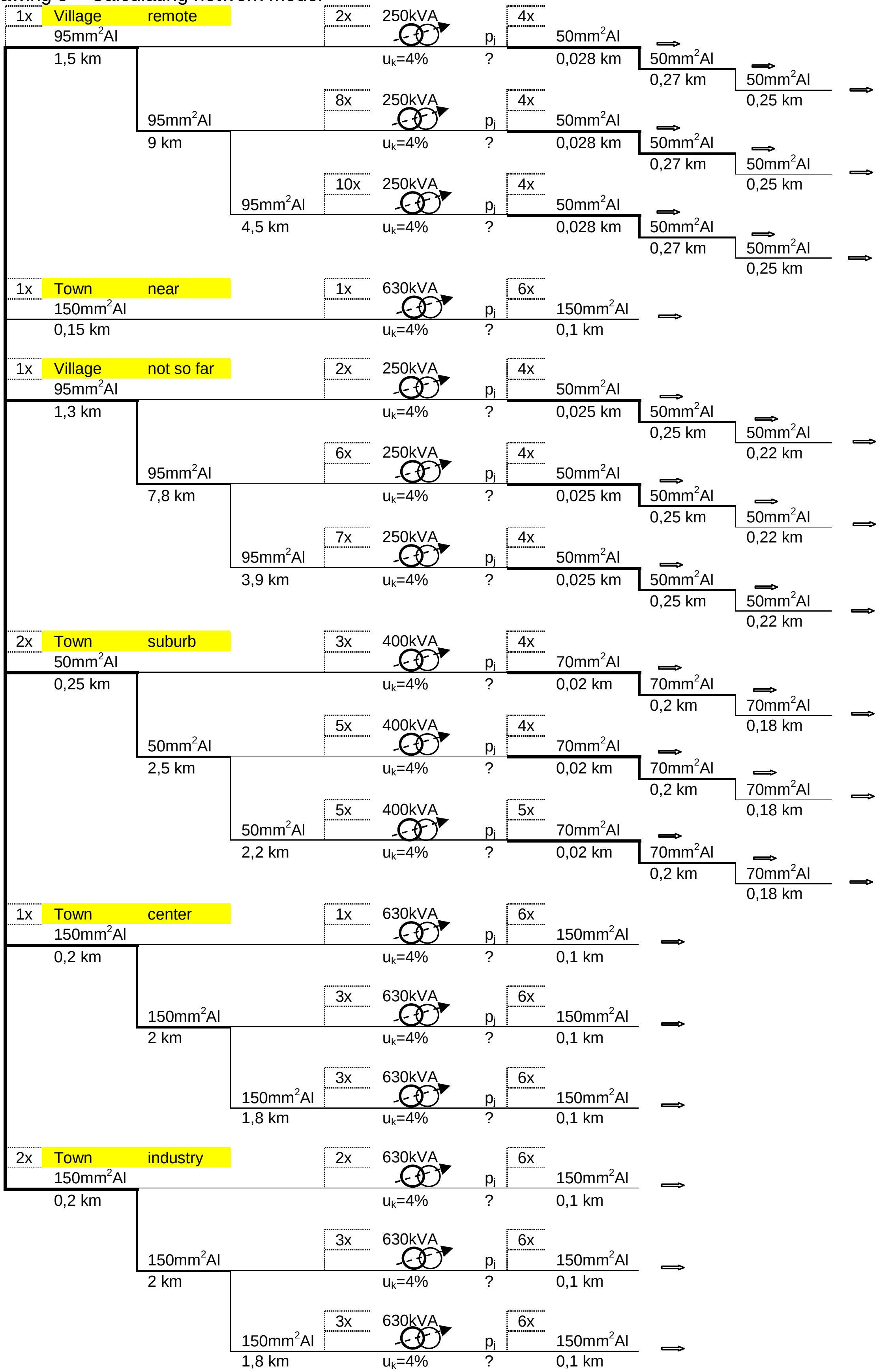


CALCULATION

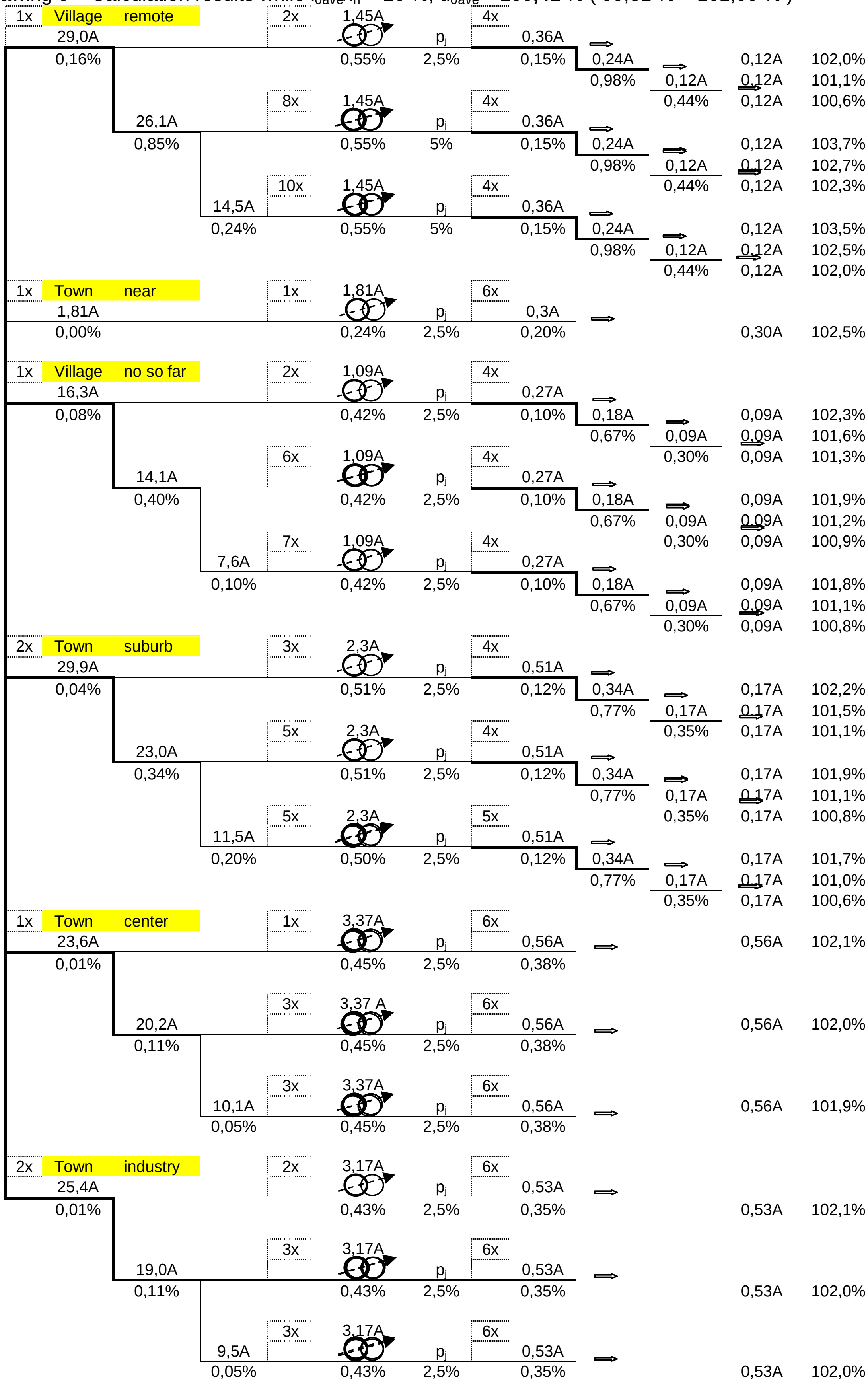
Network model and results.

Model (Drawing 5) is simplified: a) transfosmers 20/0,42 kV and consum 0,4 kV topologic grouping in a begining, middle and end 20 kV and 0,4 kV lines; b) by using standard parameters of network (line lengths, conductor cross sections, transformer number, transformer power ...). Marks: “1x” “2x” ... are numbers 20 kV lines, transformers 20/0,42 kV and 0,4 kV lines. There are two 20 kV lines in the model with very different needs for transformer tapping boost: “Village remote” with the biggest and “Town near” with the smallest voltage sag in 20 kV and in 0,4 kV network too. While average transformer 110/21 kV load i_{0ave}/i_n = 20 % (i_0 = 106 A – 255 A, i_{0ave} = 182 A, i_n = 910 A) and 60 % (i_0 = 319 A – 764 A, i_{0ave} = 546 A, i_n = 910 A) are determined optimal average source voltages (u_{0ave}), transformer tapping boost (p_j), average voltage sag in lines and transformers and voltages in customer 0,4 kV connection places (Drawings 6 i 7). Source 20 kV network voltage dependence on source 20 kV network current is determined (Drawing 8).

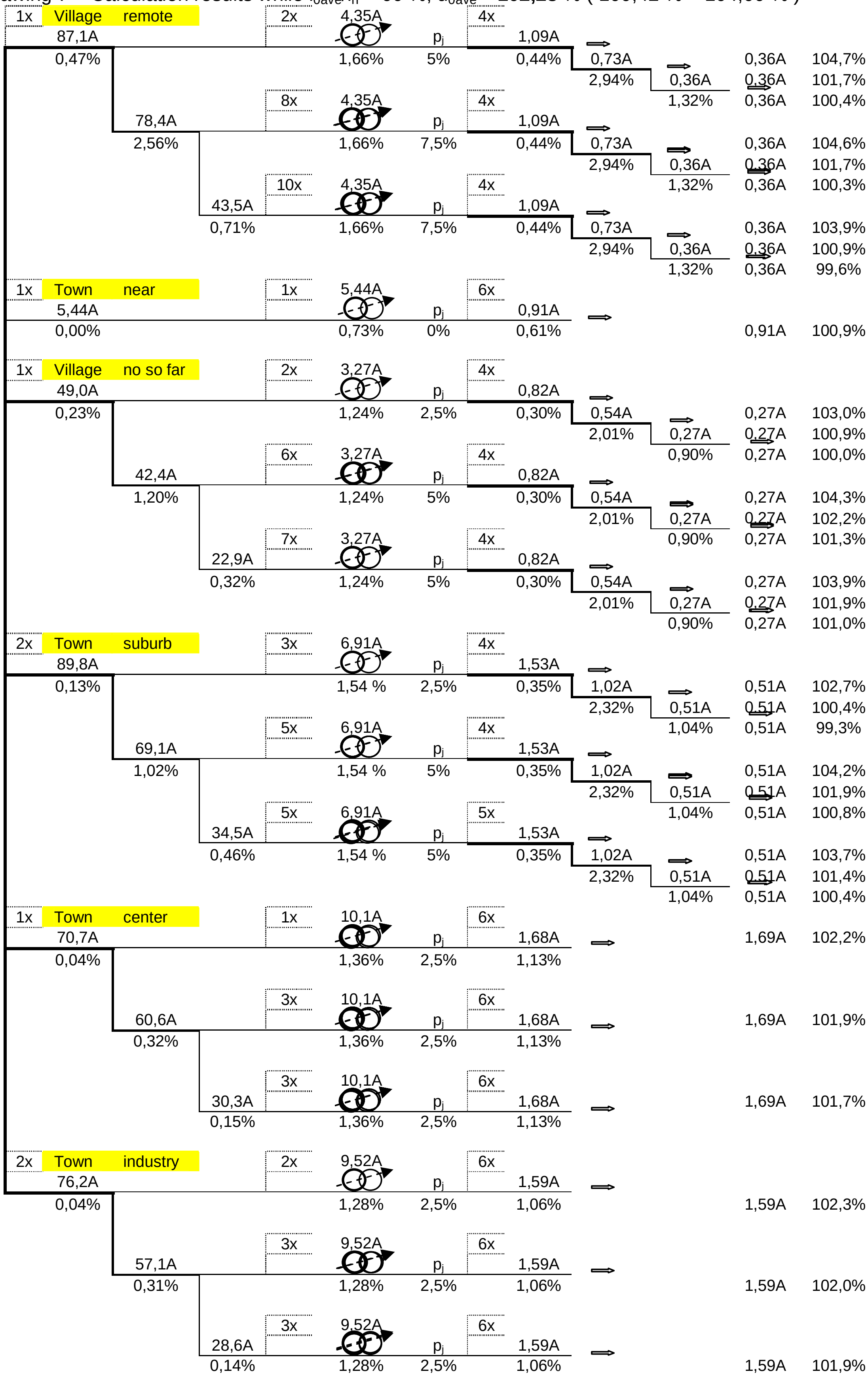
Drawing 5 – Calculating network model



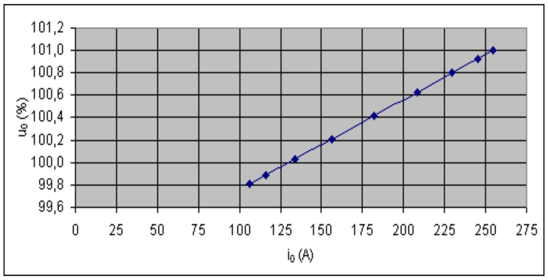
Drawing 6 – Calculation results while i_{0ave}/i_n = 20 %, u_{0ave} = **100,41** % (99,81 % – 101,00 %)

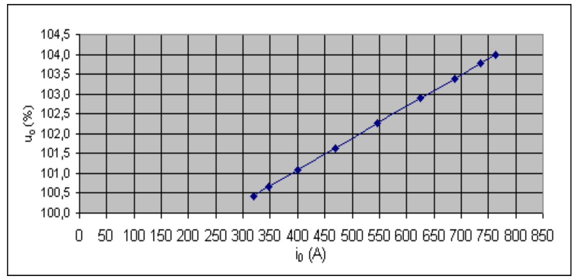


Drawing 7 – Calculation results while i_{0ave}/i_n = 60 %, u_{0ave} = **102,23** % (100,42 % – 104,00 %)



Drawing 8 – Function u_0 (%) = f (i_0 (A)) when i_{0ave}/i_n = 20 % i i_{0ave}/i_n = 60 %





Results comment.

In a transformer 110/21 kV exploatatation time beginning engaged transformer tapping boost structure is satisfy because positions 1 and 5 are not engaged. At the end of exploatation time when load catch maximal value (60 %) apeare positions 1 and 5. If maximal value 20 kV network source voltage u_{0ave} increase, in order to reduce current / network losses, then if it is less than 2,5 % damage is bigger and if it is equal 2,5 % damage has the equal – minimal value and all transformer tapping boost values fall down at one step (- 2,5 %). While is i_{0ave}/i_n = 60 %, average value 20 kV network source voltage u_{0ave} = 104,00 % is better than 106,50 % or 101,5 %, in order to reduce engaging positions 1 and 5.

Table 1 – Engaged transformer's 20/0,42 kV regulating positions structure and network 20 kV source average voltage u_{0ave} in dependence on average load i_{0ave}/i_n

Transformer 110/21 kV average load i_{0ave}/i_n	Transformers number with voltage regulation position (structure)					Source 20 kV network voltage average u_{0ave}	All customer's whole damage
	1	2	3	4	5		
(%)	(1)	(1)	(1)	(1)	(1)	(%)	(1)
20	0	67	18	0	0	100,44	1
60	1	31	35	8	10	102,32	13,04

Transformer 110/21 kV load during many year time increases and minimal possible whole damage increases 13,04 times. Network development hasn't took into consideration.

Voltage, voltage sag in lines and transformers and transformer taping boost p_j, average values.

Table 2 – Voltages, voltage sag and transformer tapping boost (average load is i_{0ave}/i_n = 20 %)

20 kV line	u_0^r	$\Delta u_{20\ kV}$	$\Delta u_{20/0,42\ kV}$	p_j	$\Delta u_{0,4\ kV}$	u
	(%)	(%)	(%)	(%)	(%)	(%)
Village remote	100,41	1,05	0,55	4,75	0,95	102,62
Town near	100,41	0,00	0,24	2,50	0,20	102,50
Village not so far	100,41	0,47	0,42	2,50	0,65	101,34
Town suburb	100,41	0,38	0,51	2,50	0,75	101,28
Town center	100,41	0,13	0,45	2,50	0,38	101,97
Town industry	100,41	0,11	0,43	2,50	0,35	102,03

Table 3 – Voltages, voltage sag and transformer tapping boost (average load is i_{0ave}/i_n = 60 %)

20 kV line	u_0^r	$\Delta u_{20\ kV}$	$\Delta u_{20/0,42\ kV}$	p_j	$\Delta u_{0,4\ kV}$	u
	(%)	(%)	(%)	(%)	(%)	(%)
Village remote	102,23	3,13	1,66	7,25	2,84	101,84
Town near	102,23	0,00	0,73	0,00	0,61	100,90
Village not so far	102,23	1,42	1,24	4,67	1,94	102,27
Town suburb	102,23	1,09	1,54	4,42	2,24	101,77
Town center	102,23	0,38	1,36	2,50	1,13	101,86
Town industry	102,23	0,33	1,28	2,50	1,06	102,04

Technical voltage borders checking.

Technical voltage borders checking (Drawing 9 – path from source to last customer marked). Voltage actual - instantaneous value in every node 0,4 kV network ($u_{ave.}$ = 99,6 %) we can determine at any network load i_0. All current and voltage sag values in network are 1,42 times bigger in maximal (peak) load than average values shown in Drawings 6 i 7 – and 0,58 in minimal load. Get the 20 kV network source voltage from diagram (Drawing 8). u (%) = u_0 - Δu_{20kV} – $\Delta u_{20/0,42kV}$ + p_j - $\Delta u_{0,42kV}$.

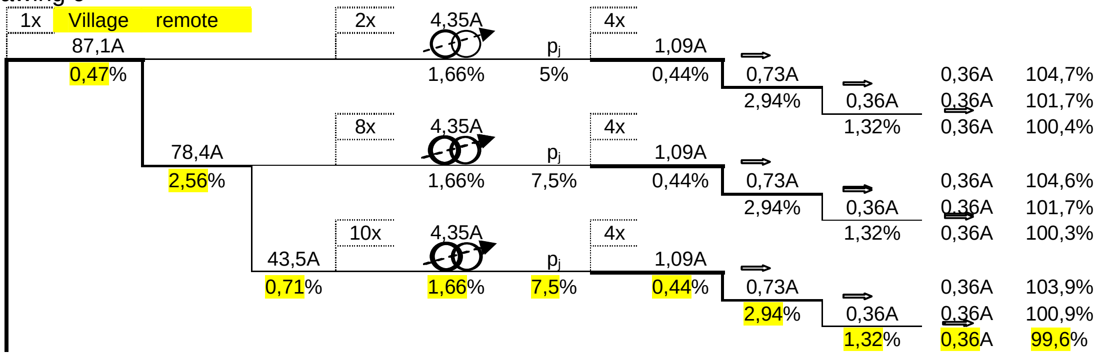
At maximal load:

u (%) = (104,00 - 1,45*(0,47+2,56+0,71) - 1,45*1,66 + 7,5 - 1,45*(0,44+2,94+1,32)) % = 96,85 %

At minimal load:

u (%) = (104,00 – 0,58*(0,47+2,56+0,71) - 0,58*1,66 + 7,5 - 0,58*(0,44+2,94+1,32)) % = 105,64 %

Drawing 9



Whole damage in 110/21 kV transformer consum reducing possible measures analysis.

Analyzed damage change by parameter distributing network model vary and using unic application:

Transformer 20/0,42 kV number increasing at 50 % (from 20 to 30) in line “Village remote” is reducing whole consum damage in 110/21 kV transformer consum at 16 %. Transformer 20/0,42 kV 0,4 kV line number increasing at 50 % (from 4 to 6) in 20 kV line “Village remote” is reducing whole damage at 10 %. These measures cause less effect in other 20 kV lines.

Transformer 20/0,42 kV 0,4 kV lines cross section increasing at 40 % (from 50 to 70) in 20 kV line “Village remote” is reducing whole damage at 6 %.

Lines 20 kV cross section increasing is no reducing whole damage. Whole damage change is unexpecting value by changing 20 kV line cross section in one 20 kV line and could be positive or negative. One’s more transformer’s 110/20 kV 20 kV line for supplying “Village remote” consum, whole consum damage reduces at least at 5 %. There are unexpecting results.This is, probably, because of 20 kV (and in 0,4 kV) network voltage sag is completely compensed by suitable optimal transformer 20/0,42 kV tapping boost. In average load equal 60 % period, engaging regulating resource big differences in Town near and Village remote supplying network are partly decrease, but not comletely. Engaged transformer tapping boost structure has improved only in local area – in 20 kV line.

CONCLUSION

Basic distributing network regulation resource optimal engaging.

Network 20 kV sources optimal values (99,8 do 104 %) are in permited borders (-10 ... +10 %). Transformer tapping boost optimal engaging structure (Table 1) is in transformer 20/0,42 kV regulating resource borders. Network 20 kV i 0,4 kV voltages are in permited borders (-10 ... +10 %).

Distributing network planning process criteria widening and corresponding measures propose.

0,4 kV network voltage sag reducing measures in lines “Village remote”, “Town suburb” and “Village not so far” gives the best effecte in whole consum damage reducing. Measures are: transformer 20/0,42 kV number increasing, transformer 20/0,42 kV 0,4 kV lines number increasing and 0,4 kV network cross section increasing. All attempts 20 kV network voltage sag reducing give no effects. Consequently, the only planning stuf obligation is to take care 20 kV network voltage sag value in line “Village remote” do not over 10 %, which transformer tapping boost maximal value compenses.

LITERATURE

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KEY WORDS

Distributive, network, regulation, voltage deviation, damage, recommended voltage, branch, node, voltage sag, tapping boost, source, special relative unit system, model, optimisation, planning.