Assessment of the Safety Conditions from High Touch and Step Voltages in the Grounding Systems of Distribution Network

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Abstract: **In this paper are described and elaborated mathematic models which are applied for solution of problem with transfer of potential in the distribution systems. Appropriate algorithm is made as programmed package which is used for analysis or better says, for anticipation of the conduct of all grounding system (GS) in the area of the TS 110/20 kV "Gostivar" when faults to ground appeared in the system 110 kV**

Keywords: **groundings, transferred potentials, safety conditions, touch and step voltages**

I. Introduction

The distribution system (DS) in Gostivar is radial distribution network which is supplied by TS 110/20 kV/kV Gostivar. Most of the medium voltage (MV) from this distribution network presents cable network with isolated metallic shield (XHP, XHE) and a small part, with transmission lines without protective rope. So all objects in part of DS (TS 110/20 kV/kV, TS 20/0,4 kV/kV, metallic shield of MV cables, copper rope and FeZn tapes) are mutual galvanic harnessed and together with their groundings, they formed GS of these distribution network. Transmission lines without protective rope do not take part from the GS of this distribution network. At appearance of fault to ground at station 110/20 kV/kV of the DS or the network 110 kV in nearness of the DS, that power is distributed at all GS. The problem with transfer of potentials is expressed with the metallic shield of cable network, as and substation TS MV/LV by 20 kV network in DS, where groundings of that TS are sources of current field and dangerous voltage of touch and step.

II. Grounding System - Model

Modelling of Cables 20 kV

Cables largely affect on features of GS in distribution network. They create connections between groundings of substations (with isolated metallic shield). Cables with conductive to ground metallic shield are behavior as groundings in GS. As a part of GS cables can be:

1. cables without metallic shield or cables with isolated metallic shield,
2. cables with conductive to ground metallic shield
3. cables placed with copper rope or Fe Zn tape.

Cable with length l placed between two substations 1 and 2 can be presented by distributed parameters as a chain of π four-extremities. Each of the four-extremities consists of a per unit length impedance $\underline{z} = r + jx$ calculated according to the Carson's relations [1], and two admittance's to ground per unit length $\underline{y}$. These admittances are nearly equal to the conductivity of a horizontal ground grid in shape of a tape with a equivalent diameter of the cable's shield d placed on a depth H with length l and they are calculated according to:

$$R_Z = \frac{\rho}{\pi \cdot l} \cdot \ln \frac{l}{\sqrt{h \cdot d_k}} \; (\Omega), \qquad (1)$$

$$\frac{Y}{l} = \frac{1}{R_Z \cdot l} = \frac{\pi}{\rho} \cdot \frac{l}{\ln\left(l / \sqrt{h \cdot d_k}\right)}, \qquad (2)$$

$$\underline{y} = \left(\frac{Y}{l}\right)_{l=1000m} = (g + jb), \qquad (3)$$

$$b = 0; \quad g = \frac{\pi}{\rho} \cdot \frac{1000}{\ln\left(l / \sqrt{h \cdot d_k}\right)}, \left(\frac{S}{km}\right) \qquad (4)$$

By applying the equation for lines with distributed parameters

$$\underline{U}_1 = \underline{U}_2 \cdot ch\underline{\gamma}l + \underline{Z}_C \cdot \underline{I}_2 \cdot sh\underline{\gamma}l,$$
$$\underline{I}_1 = \frac{\underline{U}_2}{\underline{Z}_C} \cdot sh\underline{\gamma}l + \underline{I}_2 \cdot ch\underline{\gamma}l. \qquad (5)$$

where the distribution constant $\underline{\gamma}$ and the characteristic impedance of the shield of cable $\underline{Z}_C$ are calculated from:

$$\underline{\gamma} = \sqrt{\underline{z} \cdot \underline{y}} = \sqrt{(r + jx) \cdot g} = (\alpha + j\beta) \qquad (6)$$

$$\underline{Z}_C = \sqrt{\frac{\underline{Z}}{\underline{Y}}} = \sqrt{\frac{\underline{z}}{\underline{y}}} = \sqrt{\frac{r + jx}{g}} \qquad (7)$$

The cable can be examined as π four-extremities, Figure 1.

$$\underline{Z}_P = \underline{Z}_C \cdot sh\underline{\gamma}l \qquad (8)$$

$$\underline{Y}_P = \frac{ch\underline{\gamma}l - 1}{\underline{Z}_C \cdot sh\underline{\gamma}l} \qquad (9)$$

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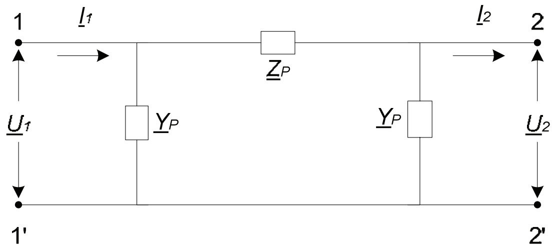

Figure 1. π four-extremities

According to [1] cables with isolated metallic shield placed without copper rope, can be presented with I-removal scheme, i.e. with one ordinal impedance $\underline{Z}_P = \underline{z} \cdot l$, $\underline{Y}_P = 0$.

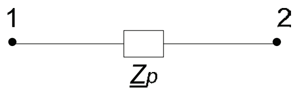

Figure 2. I-removal scheme

If cables are placed with copper rope can be examined as π four-extremities with parallel impedances ($\underline{Z}_{P1}, \underline{Z}_{P2}$) and two placed admittances to ground parameters ($\underline{Y}_{P2}$):

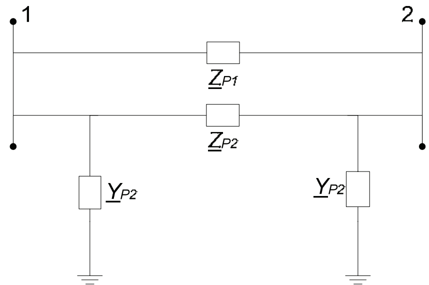

Figure 3. π four-extremities when cables are placed with copper rope or Fe Zn tape

$$\underline{Z}_P = \underline{Z}_{P1} \| \underline{Z}_{P2} \quad (10)$$

$$\underline{Y}_P = \underline{Y}_{P2}, \underline{Y}_{P1} = 0 \quad (11)$$

Modelling of Groundings on TS 20/0,4 kV/kV

Each TS 20/0,4 kV/kV which has own grounding with known grounding resistance *R*, in removal scheme of GS will be node, so-called "grounding place", and will be modelled with cross located active resistance *R*.

Groundings on TS 20/0,4 kV/kV in DN Gostivar are 7 types.

Type 1: Grounding on build TS 20/0,4 kV/kV, 500x500 cm.

Type 2: Grounding on mounted concrete TS 20/0,4 kV/kV for one transformer (400 (600) kVA), 452x284 cm.

Type 3: Grounding on mounted concrete TS 20/0,4 kV/kV for one transformer (630 (1000) kVA), 484x322 cm.

Type 4: Grounding on mounted concrete TS 20/0,4 kV/kV for two transformers (2x630 (1000) kVA), 584x484 cm.

Type 5: Grounding on tin TS 20/0,4 kV/kV 1 Tr 180x270 cm

Type 6: Grounding on pillar TS 20/0,4 kV/kV (grid, concrete, wooden), dimensions 180x180 cm.

Type 7: Grounding on adapted TS 20/0,4 kV/kV

III. Estimation-Currents and Potentials

When one-phase fault to ground appear at station 110/20 kV/kV "Gostivar" of the DS or the network 110 kV in nearness of the DS, comes to flux of currents per grounding of station, and the potential of grounding, V_g. The analyses with MATLAB show that most unfavourable case, from aspect of the quantity of potential of grounding, is for one-phase fault to ground produced in the station. The whole current of fault doesn't go into the earth, but just one part of it, which will be indicated with I_{gf}. This current in different ways, flows through earth to source of current.

In the paper it is supposed that current on fault to ground is known, produced in TS 110/20 "Gostivar". Data for value of the current of one-phase fault to ground in power system of R.M. are received from AD Mepso. The current I_{gf} =8100 A that is injected in GS in DS is calculated like in [7]. After that, by known (calculate or measured) value of fault current we can determine potentials for all groundings in the region of the DS. In the algorithm according to [2] is used matrix approach for solution of the problem of distributing of currents and transfer of potentials in GS in the DS. Solution of mentioned problem is done with help of matrix of impedances, [*Z*], of GS. For this purpose, primary, according to known plot of feeder 20kV and their known parameters, is generated so-called matrix of admittances [*Y*] of GS.

$$[Z] = [Y]^{-1} \quad (12)$$

Then, potentials $\underline{V}$(j=1,….n), of the separate groundings are:

$$\underline{V}_j = \underline{Z}_{ji} \cdot \underline{I}_i \quad (13)$$

IV. Results of the Estimation

Different types of groundings of TS MV/LV which are represented in the distribution network, in model network are represented as a concentrated active resistance Table 1.

Details are developed and established appropriate models for power cables with isolated metallic shield type XHP 48-A and XHE 49-A. Here we consider two cases:

1. When cables with isolated metallic shield are placed with copper rope, the results are in the Table 2
2. Cables with isolated metallic shield are placed without copper rope, the results are represented in the Table 3

Table 1 Characteristics of the protective groundings on TS 20/0.4 kV, connected on the TS 110/20 kV Gostivar

Num.	Type	Rz[Ω]	Ed[%]	Ec[%]
1	Type 1	5,04	27	15
2	Type 2	3,812	18	14
3	Type 3	4,19	17	13
4	Type 4	3,756	18	13
5	Type 5	4,65	15	13
6	Type 6	6,22	16	15
7	Type 7	2,76	16	12
8	TS 110/20	0,7	12	7

Table 2 Voltage and current values in GS, case 1

TS	Name	U(V)	Ed(V)	Ec(V)	Iz(A)
1	TC 110/20kV Gostivar	258	30,96	18,06	368
2	Magacini	118	21,24	16,52	31
3	Industriska Zona	109	29,43	16,35	22
4	Mlekara	106	19,08	14,84	28
5	Zac	0	0,00	0,00	0
6	Gudalat	0	0,00	0,00	0
7	Pitanica	48	8,16	6,24	12
8	Pitanica 1-Vukica	33	5,61	4,29	8
9	Pitanica 2-Kula	24	6,48	3,60	5
10	Javor	17	3,06	2,38	4
11	Stojce	14	2,10	1,82	3
12	Sv. Petka	14	3,78	2,10	3
13	Staklara 1	33	5,61	4,29	8
14	Staklara 2	32	5,44	4,16	8
15	Klanica G. Polog	24	6,48	3,60	5
16	Ciglana Nova	12	2,04	1,56	3
17	Ciglana	11	1,87	1,43	3
18	Mlin	146	24,82	18,98	35
19	Star Dekon	24	4,08	3,12	6
20	Goteks 1	20	3,60	2,60	5
21	Goteks 2	19	3,42	2,66	5
22	Crkva	17	4,59	2,55	3
23	D. Vlahov	14	2,38	1,82	3
24	Mal Park	11	1,87	1,43	3
25	I. L. Ribar	9	1,53	1,17	2
26	Sreten	5	0,90	0,70	1
27	Golem Pazar 1	3	0,51	0,39	1
28	Golem Pazar 2	3	0,51	0,39	1
29	Dr. Ante	2	0,34	0,26	0
30	Vojne	1	0,17	0,13	0
31	Banjesnica	1	0,17	0,13	0
32	Medat	120	20,40	15,60	29
33	M. Stopanstvo	64	10,88	8,32	15
34	Vase	71	12,07	9,23	17
35	Pozaren Dom	44	7,48	5,72	10
36	Podrumska (Stojan)	47	7,52	5,64	17
37	Getro Zeleznicka	34	6,12	4,42	9
38	Z. Stanica	31	5,58	4,34	8
39	Det. Gradinka 2	23	3,91	2,99	5
40	Avtobuska	22	3,74	2,86	5
41	Det. Gradinka 1	8	1,20	1,04	2
42	Balindolska	4	0,72	0,56	1
43	Dobre	3	0,54	0,42	1
44	Bejta	3	0,48	0,45	0
45	7-ma Zona	214	36,38	27,82	51
46	Teh. Uciliste	107	18,19	13,91	26
47	Boro	65	11,05	8,45	16
48	G. Delcev Osmoletka	56	9,52	7,28	13
49	Cveta	66	11,88	9,24	17
50	B. Kidric	29	4,93	3,77	7
51	Meljami	29	7,83	4,35	6
52	Policija	28	4,76	3,64	7
53	Garazi	32	5,44	4,16	8
54	Posta	16	2,72	2,08	4
55	Gostirvancanka	15	2,70	2,10	4
56	JNA	11	2,97	1,65	2
57	Getro S. Banka	8	1,44	1,12	2
58	7-ma Zona 1	118	20,06	15,34	28
59	Kula	32	5,44	4,16	8
60	Sumsko	25	4,25	3,25	6
61	K. Jovanoska	21	3,57	2,73	5
62	Vodna 2	16	4,32	2,40	3
63	Mesut	15	2,70	2,10	4
64	Kulturen Dom	21	3,57	2,73	5
65	G. Delcev	26	4,42	3,38	6
66	Parapunov	28	7,56	4,20	6
67	Livadi	99	16,83	12,87	24
68	Grobista	28	4,76	3,64	7
69	Mak. Pat	25	4,50	3,50	7
70	Mlaki	23	3,91	2,99	5
71	Korab Mermer	22	5,94	3,30	4
72	6 Zona 1	18	3,24	2,52	5
73	6 Zona 2	13	2,34	1,82	3
74	6 Zona 3	12	2,04	1,56	3
75	Novo Malo	10	2,70	1,50	2
76	Kasarni Tanja	7	1,26	0,91	2
77	Bolnica	6	1,08	0,84	2
78	Gradski Park 2	6	1,02	0,78	1
79	Gradski Park 1	6	1,08	0,78	1
80	DTV Partizan	5	0,85	0,65	1
81	Sud	2	0,32	0,24	1
82	Rodna B. Trud	1	0,18	0,14	0
83	Leska Nova	1	0,17	0,13	0
84	Rizvance	55	9,35	7,15	13
85	Petko	31	5,27	4,03	7
86	Posta Semafori	25	4,25	3,25	6
87	Sumatoska	17	3,06	2,38	4
88	Sijam	9	1,53	1,17	2
89	Benz. Pumpa	6	1,02	0,78	1
90	Vodna	5	0,85	0,65	1
91	Detska Gradinka	3	0,54	0,42	1
92	Satki	3	0,54	0,42	1
93	Stadion	1	0,27	0,15	0
94	Simun-Dutlok	1	0,18	0,14	0
95	Lak Vrbjanci	1	0,17	0,13	0
96	Gimnazija	1	0,17	0,13	0
97	Dutlok 3 (Mitre)	1	0,15	0,13	0
98	Abduraim	1	0,18	0,14	0
99	Stara Bolnica	1	0,17	0,13	0
100	Gorceva Vodenica	1	0,18	0,14	0
101	Leska	1	0,27	0,15	0

Table 3 Voltage and current values in GS, case 2

TS	Name	U(V)	Ed(V)	Ec(V)	Iz(A)
1	TC 110/20 kV	1000	120,00	70,00	1429
2	Magacini	697	125,46	97,58	183
3	Industriska Zona	669	180,63	100,35	133
4	Mlekara	655	117,90	91,70	172
5	Zac	1	0,17	0,13	0
6	Gudalat	1	0,17	0,13	0
7	Pitanica	471	80,07	61,23	112
8	Pitanica 1-Vukica	409	69,53	53,17	98
9	Pitanica 2-Kula	369	99,63	55,35	73
10	Javor	339	61,02	47,46	89
11	Stojce	250	37,50	32,50	54
12	Sv. Petka	245	66,15	36,75	49
13	Staklara 1	592	100,64	76,96	141
14	Staklara 2	578	98,26	75,14	138
15	Klanica G. Polog	401	108,27	60,15	80
16	Ciglana Nova	322	54,74	41,86	77
17	Ciglana	316	53,72	41,08	75
18	Mlin	784	133,28	101,92	187
19	Star Dekon	342	58,14	44,46	82
20	Goteks 1	351	63,18	45,63	94
21	Goteks 2	341	61,38	47,74	91
22	Crkva	276	74,52	41,40	55
23	D. Vlahov	247	41,99	32,11	59
24	Mal Park	222	37,74	28,86	53
25	I. L. Ribar	208	35,36	27,04	50
26	Sreten	158	28,44	22,12	41
27	Golem Pazar 1	129	21,93	16,77	31
28	Golem Pazar 2	126	21,42	16,38	30
29	Dr. Ante	106	18,02	13,78	25
30	Vojne	99	16,83	12,87	24
31	Banjesnica	98	16,66	12,74	23
32	Medat	665	113,05	86,45	159
33	M. Stopanstvo	484	82,28	62,92	115
34	Vase	518	88,06	67,34	124
35	Pozaren Dom	411	69,87	53,43	98
36	Podrumska Stojan	411	65,76	49,32	149
37	Getro Zeleznicka	351	63,18	45,63	93
38	Z. Stanica	335	60,30	46,90	88
39	Det. Gradinka 2	296	50,32	38,48	71
40	Avtobuska	286	48,62	37,18	68
41	Det. Gradinka 1	197	29,55	25,61	42
42	Balindolska	144	25,92	20,16	38
43	Dobre	137	24,66	19,18	36
44	Bejta	136	21,76	20,40	22
45	7-ma Zona	926	157,42	120,38	221
46	Teh. Uciliste	680	115,60	88,40	162
47	Boro	542	92,14	70,46	129
48	G. Delcev Osmolet	473	80,41	61,49	113
49	Cveta	667	120,06	93,38	175
50	B. Kidric	344	58,48	44,72	82
51	Meljami	341	92,07	51,15	68
52	Policija	336	57,12	43,68	80
53	Garazi	363	61,71	47,19	87
54	Posta	263	44,71	34,19	63
55	Gostirvancanka	257	46,26	35,98	67
56	JNA	229	61,83	34,35	45
57	Getro S. Banka	200	36,00	28,00	53
58	7-ma Zona 1	782	132,94	101,66	187
59	Kula	393	66,81	51,09	94
60	Sumsko	366	62,22	47,58	87
61	K. Jovanoska	346	58,82	44,98	83
62	Vodna 2	320	86,40	48,00	63
63	Mesut	310	55,80	43,40	81
64	Kulturen Dom	345	58,65	44,85	82
65	G. Delcev	369	62,73	47,97	88
66	Parapunov	377	101,79	56,55	75
67	Livadi	677	115,09	88,01	162
68	Grobista	380	64,60	49,40	91
69	Mak. Pat	370	66,60	51,80	97
70	Mlaki	357	60,69	46,41	85
71	Korab Mermer	351	94,77	52,65	70
72	6 Zona 1	322	57,96	45,08	85
73	6 Zona 2	281	50,58	39,34	74
74	6 Zona 3	277	47,09	36,01	66
75	Novo Malo	253	68,31	37,95	50
76	Kasarni Tanja	215	38,70	27,95	57
77	Bolnica	195	35,10	27,30	51
78	Gradski Park 2	181	30,77	23,53	43
79	Gradski Park 1	174	31,32	22,62	46
80	DTV Partizan	159	27,03	20,67	38
81	Sud	114	18,24	13,68	41
82	Rodna B. Trud	102	18,36	14,28	27
83	Leska Nova	85	14,45	11,05	20
84	Rizvance	493	83,81	64,09	118
85	Petko	392	66,64	50,96	94
86	Posta Semafori	357	60,69	46,41	85
87	Sumatoska	299	53,82	41,86	79
88	Sijam	235	39,95	30,55	56
89	Benz. Pumpa	203	34,51	26,39	48
90	Vodna	187	31,79	24,31	45
91	Detska Gradinka	165	29,70	23,10	43
92	Satki	159	28,62	22,26	42
93	Stadion	83	22,41	12,45	16
94	Simun-Dutlok	77	13,86	10,78	20
95	Lak Vrbjanci	75	12,75	9,75	18
96	Gimnazija	96	16,32	12,48	23
97	Dutlok 3 (Mitre)	86	12,90	11,18	18
98	Abduraim	82	14,76	11,48	21
99	Stara Bolnica	87	14,79	11,31	21
100	Gorceva Vodenica	90	16,20	12,60	24
101	Leska	96	25,92	14,40	19

V. CONCLUSION

1. The biggest danger of transferred potentials in 110kV network in region of the distribution network at Gostivar is when fault to ground appear in TS 110/20kV/kV.
2. Using the MATLAB programming package is estimated distribution fault to ground in to the GS, fault random places on the network.
3. When cables are placed without copper rope, we can see that appear several critical points. Otherwise when cables are placed with copper rope, there are no critical points.
4. Grounding systems do not play a direct part in the normal power flow but are very important in ensuring that insulation failures can be promptly detected and isolated by proper selection of system grounding. The other major function is to ensure that no unsafe voltages appear in any external or extraneous conducting parts of an electrical system. A good knowledge of GS is necessary to design a safe system and ensuring continued safe operation.

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