ENERGO GROUP CANADA Inc.

Technical Paper

VROT-18-3(1)

(INCREASING ELECTRICAL DISTRIBUTION GRIDS ENERGY EFFICIENCIES)

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1. INCREASING ELECTRICAL DISTRIBUTION GRIDS ENERGY EFFICIENCIES, BY IMPLEMENTING NEW TECHNOLOGY FOR ELIMINATING GREY ZONES.

Utility distribution companies are often faced with problems of low quality delivered electrical energy to their consumers. The minimum quality for delivered electrical energy is defined by the **IEC EN 50160** standard, and areas that do not satisfy the EN 50160 standard are described by the term "GREY ZONES". These zones are usually defined and limited enclaves deep within distribution grids. The main reason for GREY ZONES in low voltage distribution grids is the addition of many single-phase users with larger power demands, and user's equipment that has semiconductor-controlled components. These types of consumers, demand load increases will have a large impact on unbalanced (asymmetrical) loads in low voltage distribution grids.

GREY ZONES encompass an area with a group of users, usually up to 50kVA of maximum power, in which extremely low and extremely high voltage can appear concurrently per phase due to unbalanced (asymmetrical) loads. Unbalanced loads within distribution grids causes excessive voltage drops through phase and neutral conductors, and as a result, consumers connected to the loaded phase (185V) see lower voltages, while consumers connected to a phase which is not loaded or a low loaded phase see a voltage increase (235V). This happens due to excessive voltage drops along neutral conductor. The best solution for this is to limit the increase of currents [A] within the neutral conductor in these unbalanced load working conditions, and that is the function of VROT-18-3(1).

Other traditional solutions such as erecting a new low voltage grid with shorter distances for a smaller number of consumers (North American type of grids) would significantly increase investment and overall capital cost. North American grids are based on a larger number of substations with low power and are not economically viable since a solution would require switching to a medium voltage grounded grid system. The value of the ratio between lowered and elevated voltage within phases and whether that value falls within perimeters set in the EN 50160 standard or not, primarily depends on unbalanced load degree, total loads, longitudinal resistivity of the conduits, and phase voltages at the substation.

According to the above: resolving voltage conditions for grey zone enclaves located deep within distribution grids by increasing voltage at the substation 10(20)/0.4 kV does not make sense because it cannot significantly improve voltage and it can cause an increase in voltage within low loaded phase over 253V for longer than 500ms ("ITIC" and "CBEMA"). This can cause damage to consumer equipment, so a voltage increase in the substation 10(20)/0.4kV is not recommended (See analyses on page 10, **Figure 2.1**).

One of the best solutions in solving low (low quality) voltages within low voltage distribution grids is by balancing (creating symmetry) the loads between phases. Until today, all attempts to balance loads between phases by systematically switching load connections into different phases within a given distribution grid did not give positive results. Even after these switching attempts a repeating cycle occurs where one phase will be more loaded than the other two in one period, and in the next period the phase that is the most loaded will become not loaded while the others are overloaded. It is impossible to achieve a balance of loads within three phase distribution grids with many single-phase branch connections, by mixing their connections into different phases.

Unbalanced loads between phases causes increased voltage in low loaded phase and can damage consumer equipment. Because of that it is necessary to lower voltage in the substation, but a lower voltage may impact the time required to perform any technological process requiring electrical energy. This phenomenon results in a negative situation in the electrical distribution grid and intermittent currents [A] start to appear. These intermittent currents are much larger than usual and with their value squared, and the time they last, cause additional unplanned losses.

Here is an example to better clarify the intermittent current [A] phenomenon from above:

Due to unbalanced loads, the consumer has a low voltage of 195V. (Nominal voltage would be 235V)

> To finish cooking “lunch” (technological process) an additional 27 minutes would be needed:
> $t_{is}[min] = (235/195)^2 * t_{isn}[min] = 1.45 * t_{isn}[min]$,
> $1.45 * 60 – 60 = 27[min]$

This delay in the delivery of electrical energy causes a bottleneck supply (within the time frame of these 27[min]), as additional electrical energy is needed by other consumers that are connected to the same phase within the same time interval. This causes “bad intermittence” or “latencies” where we have currents [A] that are two or more times bigger squared, and their lasting times cause additional unplanned losses for utility providers.

Up until today, the traditional solution for resolving the GREY ZONES problem is to construct a new medium voltage distribution grid and a new substation. This reconstruction of the electrical distribution grid is tied to development of existing infrastructure within the area. For urban areas with well developed infrastructure (**Figure 1**), doing this type of reconstruction would require obtaining appropriate authorizations from government institutions, attending public hearings, a large capital investment, and lengthy implementation due to complete replacement of the existing facilities.

Substations 10(20)/0.4kV in urban areas typically have nine or more low voltage connections. Over time GREY ZONES could form on any of these output branch connections. A very difficult and long process, with a large capital investment is required to resolve GREY ZONES by constructing a new medium voltage distribution grid, along with a new substation 10(20)/0.4kV, 50kVA.

The simplest and the most cost-effective solution for resolving GREY ZONES problems is by installing VROT-18-3(1) within these GREY ZONES.

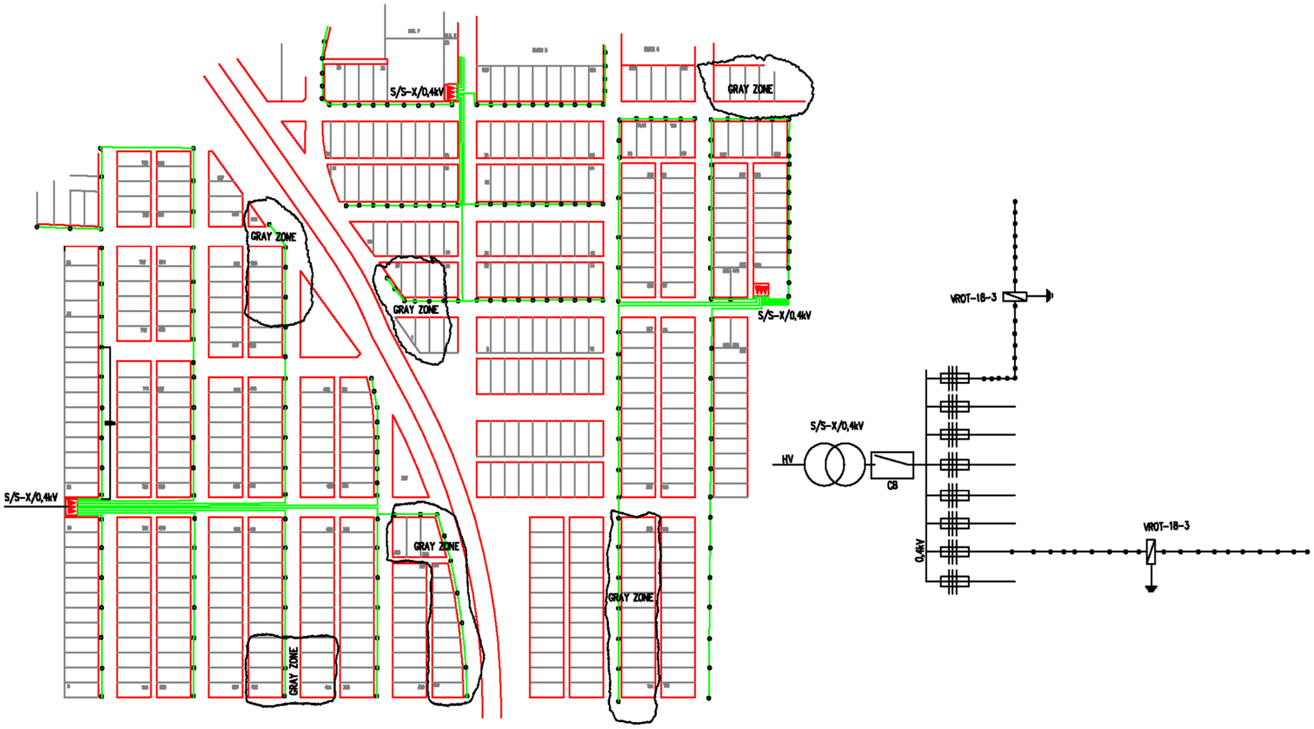


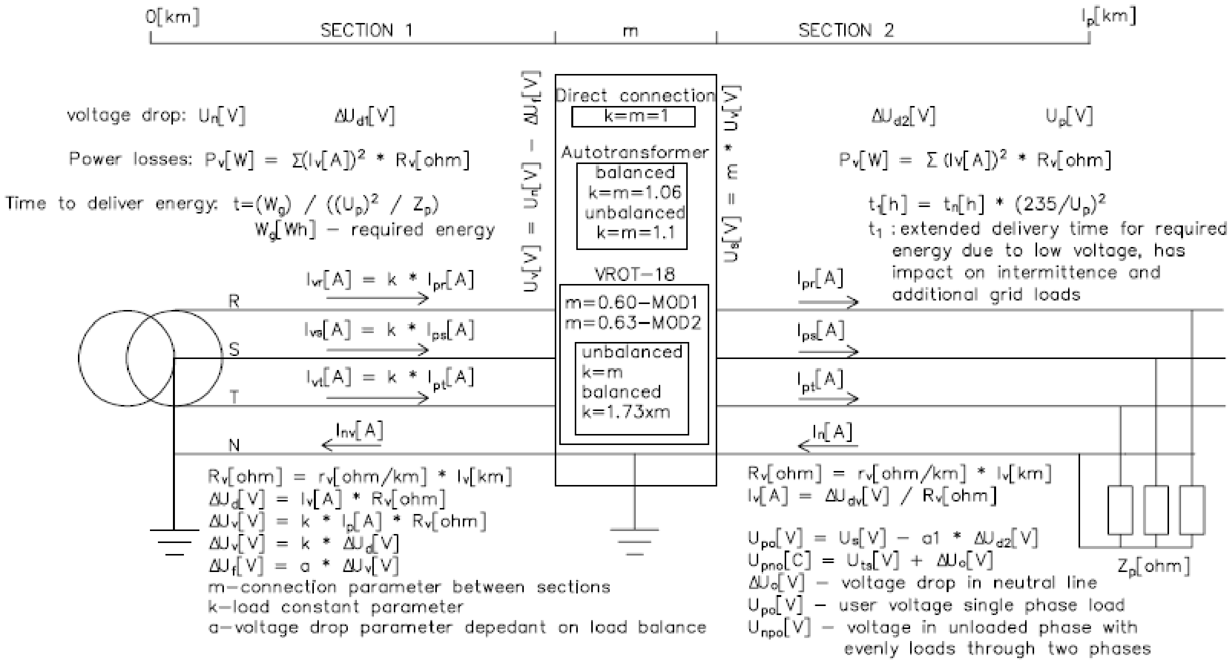
Figure 1: A Grey Zone is an area with power quality not meeting the IEC EN 50160 standard

The main causes of GREY ZONES within existing grids are the constant growth of power demand, which comes from the addition of new consumer connections, and larger load requirements coming from existing consumers. The new innovative VROT-18-3 technology guarantees a solution with a significantly smaller capital investment and much quicker implementation.

In rural areas where the electrical distribution grid was built over 50 years ago, there are factors that come from the fundamental design at the time which significantly impact voltage quality (165V) in terms of the EN50160 standard. These include the assumption that there would be a constant and small number of consumers, that the consumers would be sparsely located, and that the connections to the grid are all single-phase and far away from the substation.

Reconstruction of grids in rural areas or construction of new grids (medium voltage grid with a new substation) would require a huge capital investment without any possibility for return as there are not enough consumers. Apart from that, we would encounter the same problem of voltages deviating from the EN 50160 standard, since single-phase consumer groups are far apart. One of the simplest solutions would be the installation of VROT-18-1 system, achieving great financial savings by having a smaller capital investment, and benefiting from fast realization of the project.

a. Analyses of possible solutions to achieve quality electrical energy supply.



voltage drop	balanced load							voltage drop $\Delta U_{d2}[V]=5$	
$\Delta U_{d1}[V]=20$	m	k	a	I_{nv}[A]	ΔU_v[V]	$U_v[V]=U_n[V]-\Delta U_f[V]$	$U_s[V]=m*U_v[V]$	a1	$U_p[V]=U_s[V]-\Delta U_{d2}[V]$
Direct conn.	1	1	1	0.0	20.0	235[V]–20.0[V]=215.0	215.0	1	210.0
Autotransf.	1.06	1.06	1	0.0	21.2	235[V]–21.2[V]=213.8	226.6	1	221.6
VROT–18	0.63	1.09	2	0.0	21.8	406.5[V]–43.6[V]=362.9	228.6	1	223.6

voltage drop	unbalanced load							voltage drop $\Delta U_{d2}[V]=5$		
$\Delta U_{d1}[V]=20$	m	k	a	I_{nv}[A]	ΔU_v[V]	$U_v[V]=U_n[V]-\Delta U_f[V]$	$U_s[V]=m*U_v[V]$	a1	U_{po}[V]	U_{pno}[V]
Direct conn.	1	1	2	$k*I_p$[A]	20.0	235[V]–40.0[V]=195.0	195.0	2	185.0	235+20+5=260
Autotransf.	1.1	1.1	2	$k*I_p$[A]	22.0	235[V]–44.0[V]=191.0	210.1	2	200.1	235+22+5=262
VROT–18	0.6	0.6	2	0.0	12.0	406.5[V]–24[V]=382.5	229.5	2	215.5	235+5=240

NOTE: THE LOW VOLTAGE DISTRIBUTION GRID WILL BE IN COMPLIANCE WITH THE STANDARD EN50160 IF THE SYSTEM IS STABLE. The System will be STABLE only if the voltage values are within the limits defined by EN50160 for booth balanced and unbalanced loads within analyzed low voltage distribution grid.

Figure 2: VROT - the best solution in comparison to other methods

In **Figure 2** we show analyses in a low voltage electrical distribution line that we divided into two sections. The connection between the two sections is defined by parameter “m”. Depending on the value of parameter “m” we can differentiate:

- Direct connection (two sections of the conductor are shorted with the same conductor), m=1
- Auto transformer (two sections connected through autotransformer),
  m=1.06 – first step or m=1.1 – second step
- VROT-18 (two sections connected by VROT-18)
  M=0.6 – MOD1 or m=0.63 – MOD2

Here we introduce a load constant parameter “k” which defines loads within a closed circuit based on different load characteristics that could be:

- Balanced (symmetrical load) (current in neutral = 0) and
- Unbalanced (asymmetrical) load (current in phase and neutral are equal with the same phase shift)

Additionally, we introduce parameters “a” and “a1” that define load influence on voltage drop within one close circuit.

In the table shown in **Figure 2** we present the results of analyzing different connections between two sections of the line, with three distinctive cases, and load characteristics from balanced to unbalanced. The assumed voltage drop in the first section of one phase conductor is 20V, and the assumed voltage drop in the second section of the same phase conductor is 5V. We are analyzing voltage drops based on parameters “m”, “k”, “a” and “a1” and comparing results between three different connections in table in **Figure 2**.

<u>For the balanced (symmetrical) loads:</u>

i. Direct connection: m=k=1, a=1; as the circuit is closed through phase conductors and current in neutral conductor is = 0.
    - Phase voltage U_n[V] = 235,
    - Assumed voltage drop in first section is:
      ΔU_{d1} [V] = 20,
    - Correction of voltage drops due to load characteristics within first section is:
      ΔU_v [V] = k * ΔU_{d1} [V],
    - Correction of voltage drops due to load influence parameter “a” is:
      ΔU_f [V] = a * ΔU_v [V],
    - Based on the above, voltage at the end of the first section is:
      U_v [V] = U_n [V] - ΔU_f [V] = 215V,
    - Using parameter “m” connection between first and second section, voltage at the beginning of the second section is: U_s [V] = m * U_v [V] = 215,
    - Assumed voltage drop in second section of circuit current is: ΔU_{d2} [V] = 5,
    - We get voltage at the end of the second section as:
      U_p [V] = U_s [C] – a1 * ΔU_{d2} [V] = 210.

ii. Autotransformer (Booster) connection: m=k=1.06; transmission ratio of autotransformer is directly correlated to the amount of current and it is 6% higher than with direct connection. Parameter a=1; as the circuit is closed through phase conductors and current in neutral conductor is = 0.
    - Phase voltage U_n[V] = 235,
    - Assumed voltage drop in first section is:
      ΔU_{d1} [V] = 20,
    - Correction of voltage drops due to load characteristics within first section is:

  ΔU_v [V] = k * ΔU_{d1} [V],
  - Correction of voltage drops due to load influence parameter "a" is:
    ΔU_f [V] = a * ΔU_v [V],
  - Based on the above, voltage at the end of the first section is:
    U_v [V] = U_n [V] - ΔU_f [V] = 213.8,
  - Using parameter "m" connection between first and second section, voltage at the beginning of the second section is: U_s [V] = m * U_v [V] = 226.6,
  - Assumed voltage drop in second section of circuit current is: ΔU_{d2} [V] = 5,
  - We get voltage at the end of the second section as:
    U_p [V] = U_s [C] – a1 * ΔU_{d2} [V] = 221.6.

iii. VROT-18 connection: m=0.63, k=1.73*m=1.09; transmission ratio of VROT-18 is 0.63 in MOD2. With balanced (symmetrical) loads, currents are 1.73 higher through phase conductors than currents through VROT-18 which is defined by parameter "k". Parameter "a"=2 as current circuit is closed through phase conductors. Current in neutral is = 0.
  - Line voltage U_n[V]=406.5
  - Assumed voltage drop in the first section is:
    ΔU_{d1} [V] = 20,
  - Correction of voltage drops due to load characteristics within first section is:
    ΔU_v [V] = k * ΔU_{d1} [V],
  - Correction of voltage drops due to load influence parameter "a" is:
    ΔU_f [V] = a * ΔU_v [V],
  - Based on the above, voltage at the end of the first section is:
    U_v [V] = U_n [V] - ΔU_f [V] = 362.9,
    Note: we are using line voltage for required delivery of power to the consumers.
  - Using parameter "m" connection between first and second section, the voltage at the beginning of second section is: U_s [V] = m * U_v [V] = 228.6,
  - Assumed voltage drop in second section of circuit current is: ΔU_{d2} [V] = 5,
  - We get voltage at the end of second section as:
    U_p [V] = U_s [C] – a1 * ΔU_{d2} [V] = 223.6.

Based on the analyses above for balanced (symmetrical) loads we can conclude that all three distinctive cases satisfy quality of voltage in terms of the EN 50160 standard. Before we make any final conclusions on which solution is the most favourable, we must do the same analysis for unbalanced (asymmetrical) loads, as they are the most unfavourable condition within an electrical distribution grid and are present most of the time.

For the unbalanced (asymmetrical) loads:

These voltage analyses, at the end-user (consumer), are completed for two characteristic cases in low voltage distribution grids happening in real time. These are:

- Maximum loads within one phase while other two phases are without loads "U_{po}[V]"
- Maximum consistent loads in two phases while third phase is without loads "U_{pno}[V]"

i. Direct connection (see **Figure 2**): m=k=1, a=2 & a1=2; as the circuit is closed through phase and neutral conductors.

  - Phase voltage U_n[V] = 235
  - Assumed voltage drop in first section is:
    ΔU_{d1} [V] = 20,
  - Correction of voltage drops due to load characteristics "k" within first section is:
    ΔU_v [V] = k * ΔU_{d1} [V],

- Correction of voltage drops due to load influences parameter “a” is:
  ΔU_f [V] = a * ΔU_v [V],
- Based on the above, voltage at the end of the first section is:
  U_v [V] = U_n [V] - ΔU_f [V] = 195.0,
- Using parameter “m” connection between first and second section, the voltage at the beginning of second section is: U_s [V] = m * U_v [V] = 195.0,
- Assumed voltage drop in second section of circuit current is: ΔU_{d2} [V] = 5,
- We get voltage at the end of second section as:
  U_{po} [V] = U_s [C] – a1 * ΔU_{d2} [V] = 185.0.

From the above analyses we can see that during maximum loads within one phase (while the other two phases are unloaded) the voltage level at the consumer end is too low and not in compliance with EN 50160. On the other hand, the scenario where two phases are loaded and the third is unloaded, the voltage level at the consumer end on the unloaded phase is U_{pno}[V]=260 which is also not in compliance with the EN50160 standard.

ii. Autotransformer (Booster) connection (see **Figure 2**): m=k=1.1; Parameter a=2 & a1=2; as the circuit is closed through phase and neutral conductor.
   - Phase voltage U_n[V] = 235
   - Assumed voltage drop in first section is:
     ΔU_{d1} [V] = 20,
   - Correction of voltage drops due to load characteristics within first section is:
     ΔU_v [V] = k * ΔU_{d1} [V],
   - Correction of voltage drops due to load influence parameter “a” is:
     ΔU_f [V] = a * ΔU_v [V],
   - Based on the above, voltage at the end of the first section is:
     U_v [V] = U_n [V] - ΔU_f [V] = 191.0,
   - Using parameter “m” connection between first and second section, the voltage at the beginning of second section is: U_s [V] = m * U_v [V] = 210.1,
   - Assumed voltage drop in second section of circuit current is: ΔU_{d2} [V] = 5,
   - We get voltage at the end of second section as:
     U_p [V] = U_s [C] – a1 * ΔU_{d2} [V] = 200.1.

From the above analyses we can see that during maximum loads within one phase (while the other two phases are unloaded) the voltage level at the consumer end is too low and not in compliance with EN50160. The scenario where two phases are loaded and the third is unloaded, the voltage level at the consumer end on the unloaded phase is U_{pno}[V]=262, which is also not in compliance with the EN50160 standard. Applying this solution within the system would require lowering conductor resistivity by changing it to have a bigger cross section.

iii. VROT-18 connection (see **Figure 2**): m=k=0.6, parameters “a” & “a1” = 2, as current circuit is closed through phase conductors on primary side and phase and neutral on secondary side.
   - Line voltage U_n[V]=406.5
   - Assumed voltage drop in first section is:
     ΔU_{d1} [V] = 20,
   - Correction of voltage drops due to load characteristics within first section is:
     ΔU_v [V] = k * ΔU_{d1} [V],
   - Correction of voltage drops due to load influence parameter “a” is:
     ΔU_f [V] = a * ΔU_v [V],
   - Based on the above, voltage at the end of the first section is:
     U_v [V] = U_n [V] - ΔU_f [V] = 382.5V,

Note: we are using line voltage for required delivery of power to the consumers.

- Using parameter "m" connection between first and second section, the voltage at the beginning of second section is: U_s [V] = m * U_v [V] = 229.5,
- Assumed voltage drop in second section of circuit current is: ΔU_{d2} [V] = 5,
- We get voltage at the end of second section as:
  U_{po} [V] = U_s [C] – a1 * ΔU_{d2} [V] = 219.5.

From the above VROT-18 analyses we can see that during maximum loads within one phase (while the other two phases are unloaded) the voltage level at the consumer is in compliance with EN 50160. In the second scenario where two phases are loaded and the third is unloaded, the voltage level at the consumer end on the unloaded phase is U_{pno}[V]=240 which is also in compliance with the EN 50160 standard.

Based on the simple analyses above we can conclude, with sufficient accuracy, that the system will satisfy the EN 50160 standard only if it is in stable condition. When we analyze an entire distribution grid with maximum loads per phase, we are looking for a stable system that will satisfy the EN 50160 standard in both balanced and unbalanced conditions.

With the above analyses for both balanced and unbalanced loads we can conclude that the system is only in stable condition when using VROT-18 for the connection between two sections. The VROT-18 solution increases grid efficiency and can be implemented without a large capital investment. These analyses show that for direct or autotransformer connections between two sections, either the position of the voltage regulator on the power transformer needs to be on the lowest voltage on the secondary, or the conductor resistivity [Ω/km] must be changed so that the voltage level (U_{npo}[V]) would not exceed 253[V] for longer than 500ms during unbalanced loads on low loaded phases .

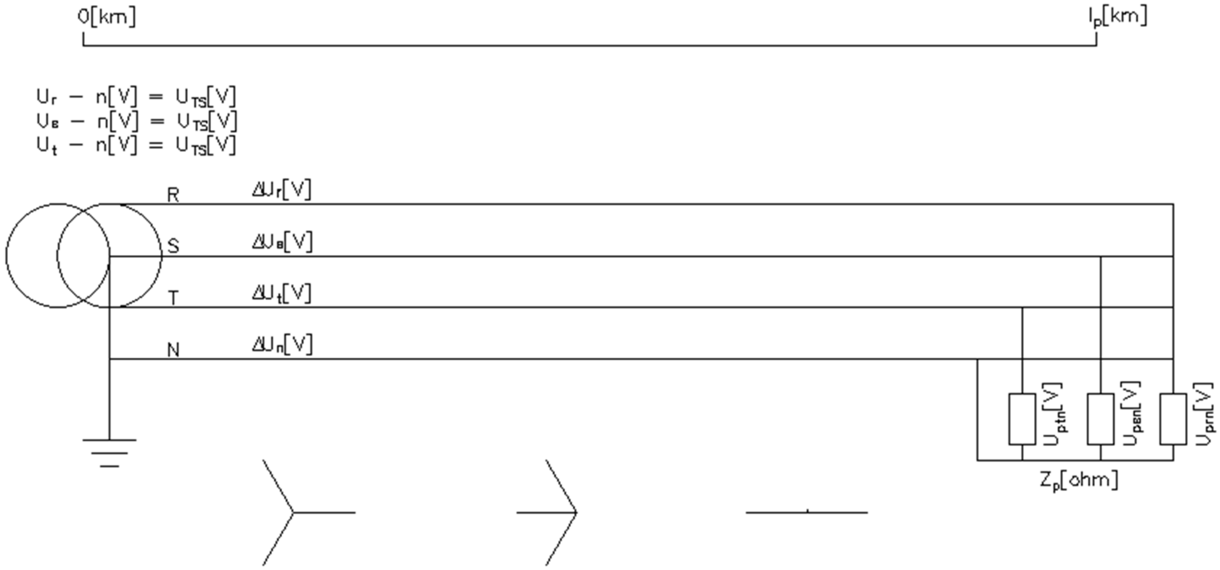
b. Boosting voltage level on power transformers within a substation to correct voltage levels at the consumer end.

Before concluding which method would provide the best results as a solution for voltage correction at the consumer end, it is necessary to analyze all characteristic load conditions within the low voltage distribution grid.

Those conditions are:

- Balanced (symmetrical) and loaded low voltage grid, all three phases concurrently loaded with equal loads.
- Unbalanced (asymmetrical) loaded low voltage grid with two possible situations:
  - Two phases concurrently loaded with equal loads; one phase not loaded
  - One phase loaded, and other two phases not loaded

This analysis is explained in **Figure 2.1**, where we can see that by increasing the voltage level at the substation "U_{ts}[V]" we cannot satisfy the voltage level as per the EN 50160 standard. On top of that, due to overvoltage appearance for the low-loaded or not-loaded phases, voltage for those consumers would need to be lowered on the secondary side of the power transformer in the substation.



ΔU[V]	balanced load		unbalanced load			
ΔU_r[V]	20		0		20	
ΔU_s[V]	20		20		0	
ΔU_t[V]	20		20		0	
ΔU_n[V]	0		20		20	
ΔU_{TS}[V]	230	240	230	240	230	240
ΔU_{prn}[V]	210	220	250.0	260.0	190	200
ΔU_{psn}[V]	210	220	200.7	210.7	240.6	250.6
ΔU_{ptn}[V]	210	220	200.7	210.7	240.6	250.6

ΔU_v[V] = 20						
r_v[ohm/km] = 0.443						
l_p[km]	0.2	0.6	0.8	1.0	1.5	2.0
Iv[A]	225.7	75.2	56.4	45.14	30.1	22.6

ΔU_v[V] – maximum voltage drop in grid per phase
r_v[ohm/km] – conductor resistivity per length
l_p[km] – distance to the consumer group from substation
Iv[SA] – single phase current (load) causing voltage drop ΔU_v[V]

Figure 2.1: Analysis of characteristic load conditions within low voltage distribution grid

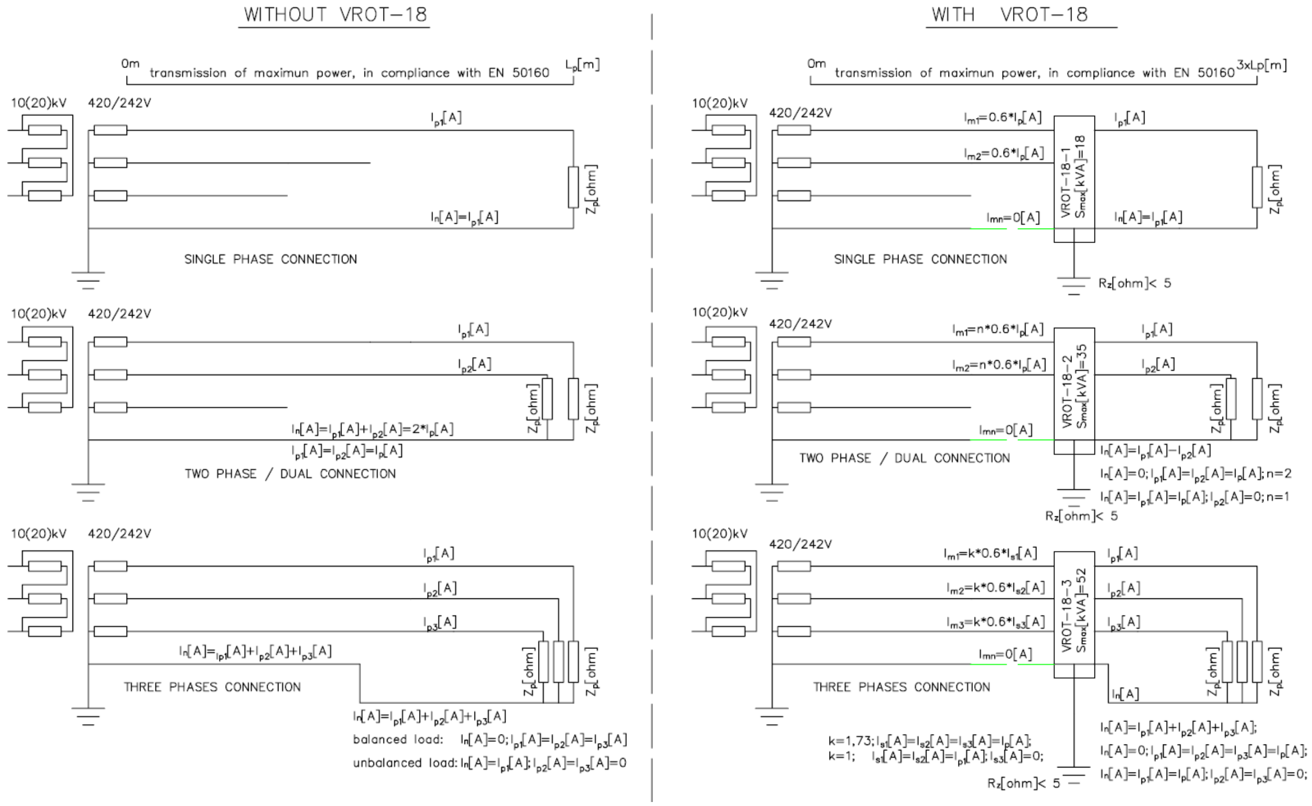


Figure 3: Three possible connection comparisons with and without VROT-18

c. Possible connections in power distribution grid applying VROT-18 solution

As shown in **Figure 3**, we can identify three different ways consumer groups connect to the grid:

- Single phase connection
- Two phase connection
- Three phase connection

Analysis was done with the assumption that the voltage at the consumer location is the same in both cases (without and with VROT-18) since this analysis addresses different load cases and power losses in distribution grids.

Current [A]	WITHOUT VROT-18			WITH VROT -18		
	Single phase	Two phases		Single phase	Two phases	
		unbalanced	balanced		unbalanced	balanced
I_{p1}[A]	63	63	63	63	63	63
I_{p2}[A]	---	--	63	---	--	63
I_n[A]	63	63	63	63	63	0
I_{m1}[A]	63	63	63	37,8	37,8	75,6
I_{m2}[A]	--	---	63	37,8	37,8	75,6
I_{mn}[A]	63	63	63	0	0	0
R_v[ohm]	0.6					
$P_{gv}[kW]=R_v*(\sum I_i)^2$ Losses in line	9.52	9.52	14.28	6.47	6.47	11.62
P_{gvs}[kW] median number	9.52	(14.28+9.52)/2=11.9		6.47	(11.62+6.47)/2= 9.04	

Table 1.

We analyze a three phase connection in **Table 2** below the same way as in **Table 1**:

Current [A]	WITHOUT VROT-18 three phase connection		WITH VROT -18 three phase connection	
	unbalanced	balanced	unbalanced	balanced
I_{p1}[A]	63	63	63	63
I_{p2}[A]	--	63	--	63
I_{p3}[A]	--	63	--	63
I_n[A]	63	--	63	--
I_{m1}[A]	63	63	37.8	65.34
I_{m2}[A]	--	63	37.8	65.34
I_{m3}[A]	--	63	--	65.34
I_{mn}[A]	63	--	--	--
R_v[ohm]	0.443			
$P_{gv}[kW]=Rv*(\sum I_i)^2$ Losses in line	7.03	10.55	4.78	10.94
P_{gvs}[kW] median number	(10.55+7.03)/2 = 8.79		(10.94+4.78)/2 = 7.86	

Table 2.

Based on the analyses shown in **Tables 1 and 2** above, we can see that the VROT-18 system solution significantly reduces overall power losses in the grid, especially if unbalanced loads are present in the distribution grid most of the time. Power losses within time of delivery of electrical energy are:

$t_{is}[h] = (U_n[V] / U[V])^2 * t_{isn}[h]$, where:

$U[V]$ – Voltage level at consumer location

$U_n[V]$ – Consumer nominal voltage

R_p [ohm] - Consumer impedance

t_{is} [h] – delivery time of electrical energy with lower voltage

t_{isn} [h] – delivery time of electrical energy with nominal voltage

Time needed to deliver required electrical energy is extremely important for grids with an intermittent regime since additional losses are generated due to bad intermittence of distribution grid.

Starting with the relation: $P_{gvi}[kW] = R_v[ohm]*(I_{vi}\ [A])^2$, where

$R_v[ohm]$ – line impedance,

I_{vi} [A]- sum of intermittent currents in line,

Intermittent currents can be two or more times bigger than usual ones, so energy used from the distribution lines $W_{gi}[kWh]= P_{gvi}[kW] * t_{is}[h]$ becomes significantly larger.

d. VROT-18-3 and VROT-18-1 solution impact to selectivity and sensitivity of grid protection:

One of the parameters which define quality of supplied electrical energy is the time period that voltage falls to zero and the number of consumers effected by this voltage drop. Consumers can experience loss of voltage by planned or unplanned power outages. Planned power outages are controlled and announced power shutoffs, where consumers can adjust their activities within that period of power shutdown. Unplanned power outages are uncontrolled; resulting from equipment failure within the distribution grid, substation etc., or other causes and their duration is not defined, nor is the number of affected consumers.

To overcome unplanned power outages and to place them into controlled timelines, utility companies are sectioning their distribution grids into smaller consumer groups. Creating grid sections and consumer protections are done by using fuses or in medium voltage lines, reclosers (switch with current and voltage sensors), so that in the case of a power outage in a certain location the number of consumers affected by that outage can be limited.

This sectioning using fuses is not very efficient as it is unreliable due to bad intermittence in distribution grids. Currents can quickly grow 2.5 times larger than the nominal cut-off fuse current settings causing the fuse to react even if there is no fault in the system. When it comes to long conductors with small cross sections (out of design capacity), and higher resistance in fuses, a fault could stay undetected and protection in the lines would not react. This is especially more noticeable in medium voltage distribution lines as they are isolated systems with small currents.

As the best solution for selectivity and sensitivity of the grid protection we can offer:

VROT-18-3 and VROT-18-1 units.

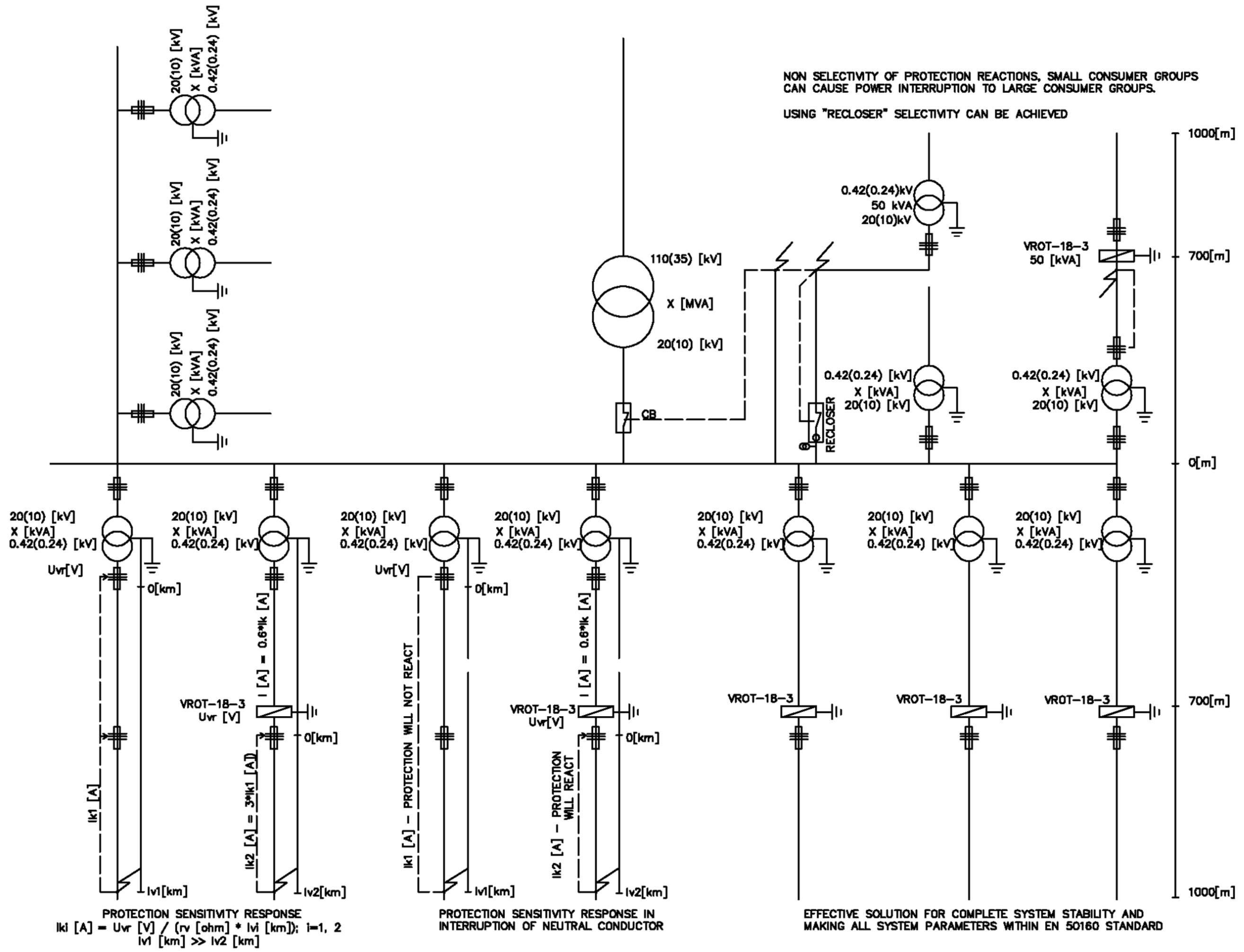


Figure 4: Protection sensitivity

Protection reaction time and its sensitivity within low voltage distribution grids are defined by a single-phase short circuit at the end of the line. The current value which will cause a protection reaction in a fuse is set to be 2.5 times the value of nominal current values (2.5 * I_{osig}[A]). This current value is defined as: $I_k[A]=U_n[V]/R_k[ohm]$, where $R_k[ohm]$ is fault resistivity and it is defined as: $R_k[ohm]= rv[ohm/km] \times l[km]$, where l[km] is distance from source (substation) to the location of the fault.

Adding fuses along the grid as shown in **Figure 4** means that the current created during fault I_{k1}[A] is constant between the fault location and the associated substation. To achieve selectivity along the grid with this protection, the fuse with a smaller current threshold and faster reaction time is usually intended to react first and to prevent the fuses in the substation from reacting. That way only a small group of users would be left without power. When the grid is energized and in the case of low voltage at consumer locations, the time to supply required electrical energy is prolonged $t_{is}[h]=(U_n[V]/\ U[V])^2 *\ t_{isn}[h]$. This causes an increase in intermittence currents that causes a protection reaction along the line. This reaction should not be allowed and will need to be prevented by using an alternative method to the fuses described above.

Installing the VROT-18 system which has built in fuse protection at its output within the grid reduces the distance between source and fault locations l[km]. With that we reduce fault resistivity that will cause an increase in current during faults $I_{k2}[A] >> I_{k1}[A]$, see **Figure 4**, and with that comes shorter recognition and reaction time to faults. On the other side, the current during this faulty condition flows through the VROT-18 and towards the substation, through the grid section between the substation and VROT-18: $I_{k3}= 0.6 \times I_{k2}[A]$,

Figure 4. Current I_{k3} is the current that causes a fuse reaction in the substation output. That fuse reaction time is much slower than fuse protection at the VROT-18 output reacting with I_{k2}[A] fault current. This way we achieve selectivity of the grid since only a small portion of the consumers (the ones fed through VROT-18) would be without power and not the entire grid. At the same time, VROT-18 improves the voltage level at consumer sites that are supplied through VROT-18 and will eliminate or reduce the chances of creating intermittent currents.

One of the most dangerous situations within live grids is a break of the neutral line in a substation. During a simultaneous break in the neutral line and a single-phase short circuit in the low voltage distribution grid, protection will not react, and the break in the neutral will expose all consumers to the line voltage instead of phase voltage. Using VROT-18 system, we increase consumer protection if there is a break in the neutral line in a substation simultaneously with single phase short circuit at the end of the low voltage line, as protection built in VROT-18 (its output fuse) will react.

Resolving GREY ZONES within low voltage grids by applying traditional methods (constructing a medium voltage distribution grid with a small power substation) will still leave this new distribution grid without selectivity protection. Small scale faults within medium voltage grids can cause a reaction in an upstream substation 110/10(20) kV, **Figure 4**, and cut-off power to the entire consumer area. Based on this we can conclude that a small fault (at a small consumer site) can cause an outage in big consumer groups and areas. To prevent this, we can apply selectivity protection by using other methods for reconstruction or adding proper protection by reclosers.

Adding medium voltage fuses at single phase branches from the main three phase grid is not efficient as these grids are isolated where currents in fault conditions are small. Constructing a medium voltage grid with an associated low power, 50kVA, substation will need reclosers protection in order to resolve GREY ZONES which is a very expensive solution.

The simplest and most economically viable solution to resolve GREY ZONES with respect to selectivity is by installing VROT-18. Installation of VROT-18-3 and/or VROT-18-1 within GREY ZONES will help in times of eventual faults in the lines to the substation by cutting off power on the output side of the low voltage substation.

e. Determining a location to install VROT-18

GREY ZONES are defined areas at the end of a low voltage of electrical distribution grid created by consumer group with maximal power up to 50kVA. To determine if a low voltage branch has a grey zone area, we can calculate that for certain consumer group at the end of the low voltage line, based on their maximum installed power, branch conductors' cross section, and their distance from the substation.

As an example, here we are analyzing one consumer group with 50kVA of power located 500m away from the substation, with grids conductors that are made of: SKS X00-Y 3x70+71.5mm^2.

S_n[kVA]=50; l_v[km]=0.5; r_v[ohm/km] = 0.443; R_v[ohm]=0.443*0.5=0.221; I_v[A]= (50/3)/0.23= 72.5;

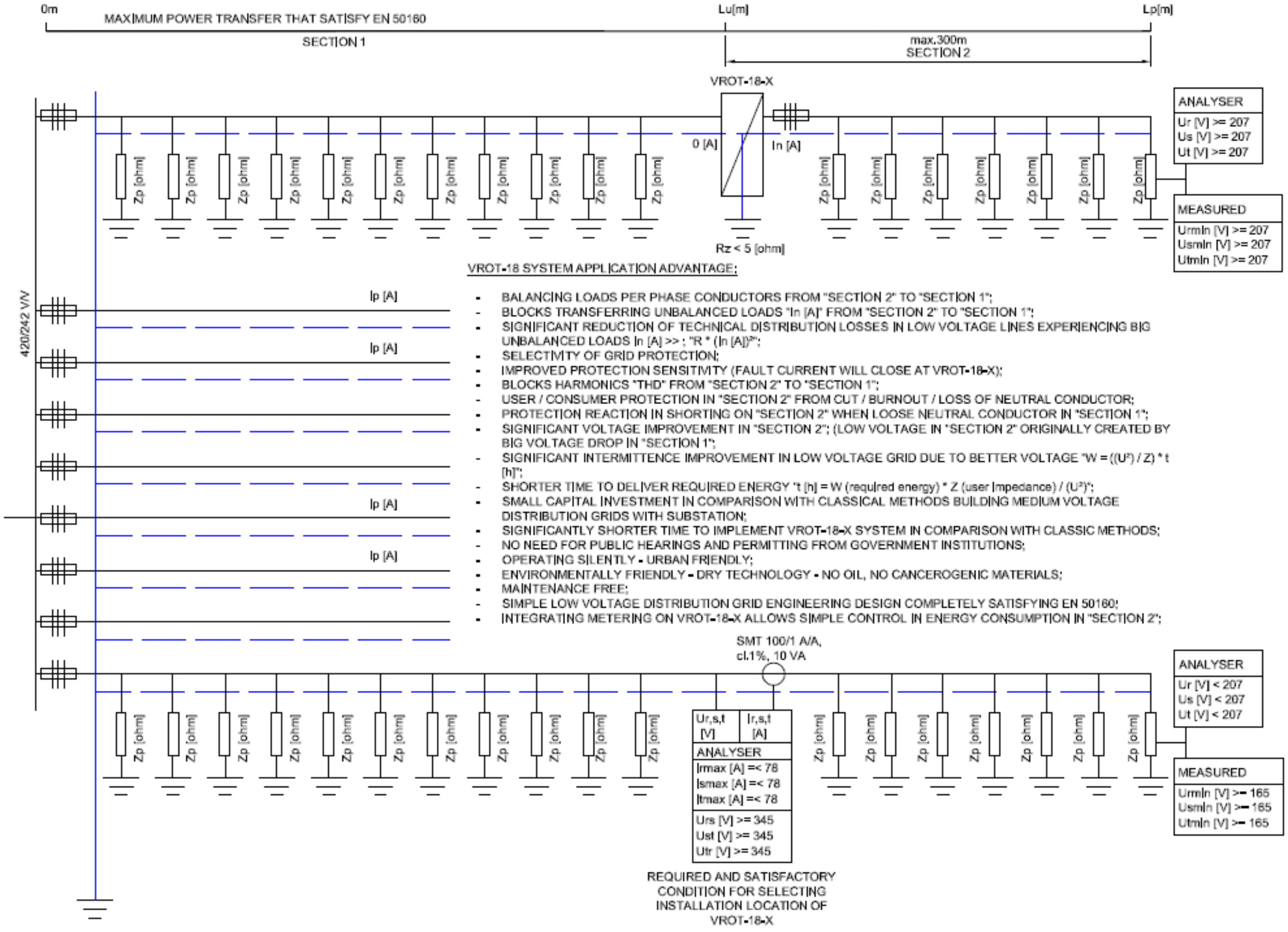
ΔU[V]=2* R_v[ohm]*I_v[A] = 2*0.221*72.5= 32.045, U_p[V]= 235-32.045= 203V < 207V.

Based on this example we would need to install an analyzer at the end of this low voltage branch at the location of the last consumer, then follow its exact procedures to record all necessary measurements. If these measurements confirm that power quality is not in accordance with the EN 50160 standard, we can start with determining the best location for VROT-18-3.

We estimate (best engineering judgment) a location within the low voltage branch in question where the maximum current is less than or equal to 78[A]. At that location we install current transformers 100/5A connected to an analyzer. See **Figure 5**.

Measured data and results from this analyzer must be within these parameters:

- Line Voltage: U_{rs}[V] ≥345; U_{st}[V] ≥345; U_{tr}[V] ≥345,
- Phase currents: I_r[A]≤78; I_s[A] ≤78; I_t[A] ≤78,
- Once these parameters are confirmed, the selected location is the most optimal location for the VROT-18-3 installation.



VROT-18 SYSTEM APPLICATION ADVANTAGE:

- BALANCING LOADS PER PHASE CONDUCTORS FROM "SECTION 2" TO "SECTION 1";
- BLOCKS TRANSFERRING UNBALANCED LOADS "In [A]" FROM "SECTION 2" TO "SECTION 1";
- SIGNIFICANT REDUCTION OF TECHNICAL DISTRIBUTION LOSSES IN LOW VOLTAGE LINES EXPERIENCING BIG UNBALANCED LOADS In [A] >> ; "R * (In [A])²";
- SELECTIVITY OF GRID PROTECTION;
- IMPROVED PROTECTION SENSITIVITY (FAULT CURRENT WILL CLOSE AT VROT-18-X);
- BLOCKS HARMONICS "THD" FROM "SECTION 2" TO "SECTION 1";
- USER / CONSUMER PROTECTION IN "SECTION 2" FROM CUT / BURNOUT / LOSS OF NEUTRAL CONDUCTOR;
- PROTECTION REACTION IN SHORTING ON "SECTION 2" WHEN LOOSE NEUTRAL CONDUCTOR IN "SECTION 1";
- SIGNIFICANT VOLTAGE IMPROVEMENT IN "SECTION 2"; (LOW VOLTAGE IN "SECTION 2" ORIGINALLY CREATED BY BIG VOLTAGE DROP IN "SECTION 1";
- SIGNIFICANT INTERMITTENCE IMPROVEMENT IN LOW VOLTAGE GRID DUE TO BETTER VOLTAGE "W = ((U²) / Z) * t [h]";
- SHORTER TIME TO DELIVER REQUIRED ENERGY "t [h] = W (required energy) * Z (user impedance) / (U²)";
- SMALL CAPITAL INVESTMENT IN COMPARISON WITH CLASSICAL METHODS BUILDING MEDIUM VOLTAGE DISTRIBUTION GRIDS WITH SUBSTATION;
- SIGNIFICANTLY SHORTER TIME TO IMPLEMENT VROT-18-X SYSTEM IN COMPARISON WITH CLASSIC METHODS;
- NO NEED FOR PUBLIC HEARINGS AND PERMITTING FROM GOVERNMENT INSTITUTIONS;
- OPERATING SILENTLY - URBAN FRIENDLY;
- ENVIRONMENTALLY FRIENDLY - DRY TECHNOLOGY - NO OIL, NO CANCEROGENIC MATERIALS;
- MAINTENANCE FREE;
- SIMPLE LOW VOLTAGE DISTRIBUTION GRID ENGINEERING DESIGN COMPLETELY SATISFYING EN 50160;
- INTEGRATING METERING ON VROT-18-X ALLOWS SIMPLE CONTROL IN ENERGY CONSUMPTION IN "SECTION 2";

Figure 5: Optimal location for VROT-18 installation

f. Use of VROT-18 within system with remote reading of revenue meters PLC/DLC

Low voltage branches that are free of grey zone areas feed power to areas where it is possible to remotely read and record revenue meters with PLC (Power Line Communication). Data transfer is limited by the number of connected consumers, conductor impedances and the quality of consumer connections to the grid. Communication between consumer meters and concentrators is possible without interruptions up to 350m. Interruptions start to happen in grid sections with revenue meters between 350m and 500m and communication stops for the distances greater than 500m.

An alternative communication solution for urban and semi-urban areas where these distances between concentrators and consumer meters are longer than 500m is done by using GPRS as they are more reliable than PLC. Areas with consumer groups of about 50kVA installed power, and which are located at a distance of

500m or more from the substation where the concentrator is installed, usually have already formed or have the potential to form grey zones.

When applying VROT-18-3 system for three phase connections or VROT-18-1 for a single phase connection within these low voltage grids, we can achieve communications with revenue meters in that area by PLC by having a concentrator built within the output of VROT-18-X unit (X=1 or 3). The concentrator installed at the output of VROT-18-X in distribution systems would be the “slave” and the existing concentrator within main substation would be the “master”. See **Figure 6**.

Data processing, depending on the software, can be done at the “slave” or “master” level. Data processing done at the “slave” level takes data from a smaller consumer group. This will give utilities the advantage of, simultaneously (without delays), comparing readings from consumer meters with VROT-18-X, a simple way of determining losses either by faulty meters or irregular connections and use.

Data processing at the “master” level does not give us this option as it is not possible or practical to get simultaneous readings from all consumer meters when the consumer groups are large. Even if that were possible, we would not know which branch has a problem.

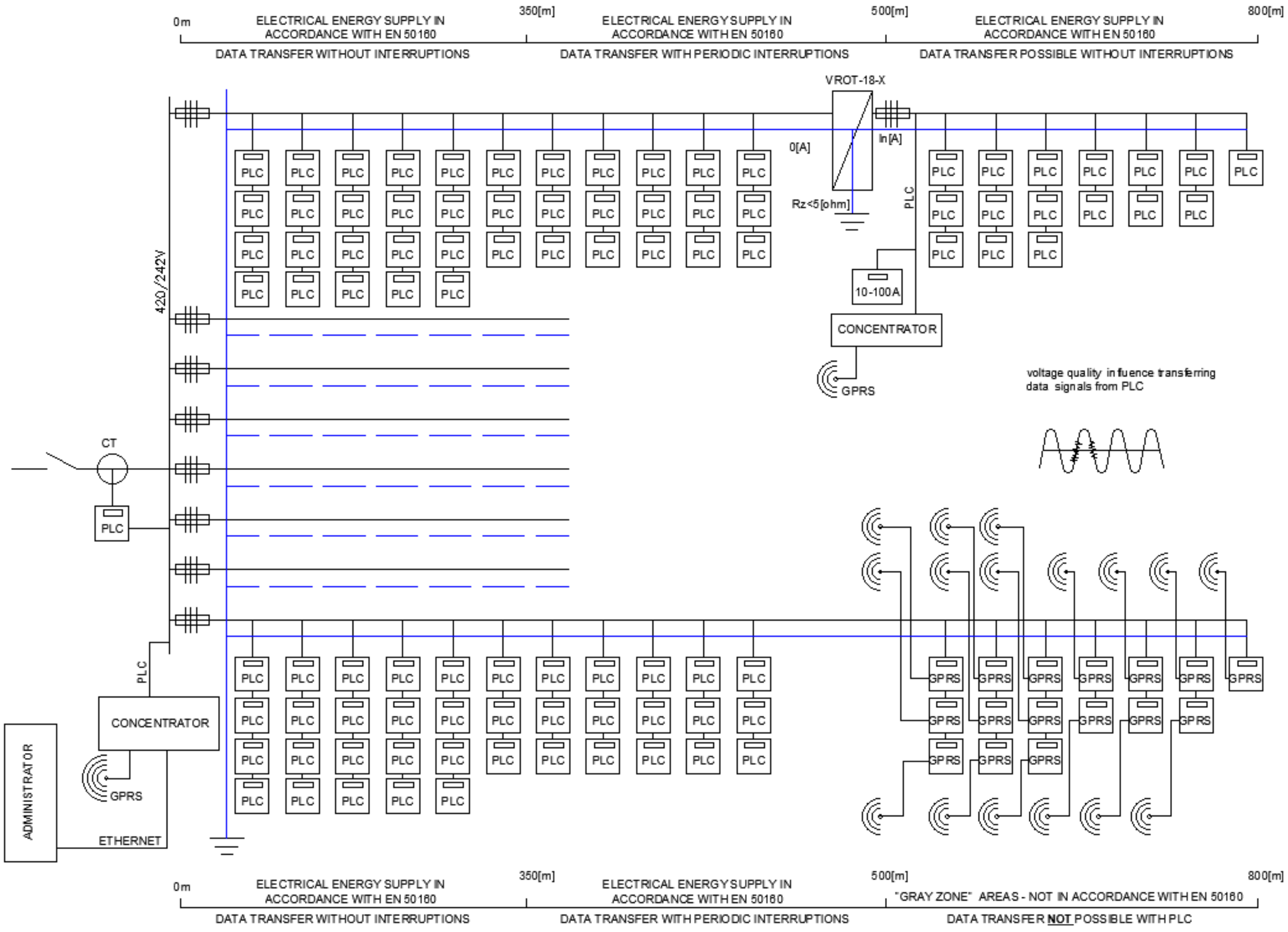


Figure 6: Remote readings of electrical energy revenue meters by PLCs with and without VROT-18-x

g. Advantages of VROT-18-X system within low voltage distribution grids:

- Balancing loads within phases along grid section between substation and installation location of VROT.
- Block transferring unbalanced currents (loads) from its secondary side into the section between the substation and installation location of VROT.

- Significant reduction of technical losses within the grid, especially within grids with many unbalanced loads.
- Selectivity protection
- Protection sensitivity
- Block transferring THD harmonics into the grid section between the substation and installation location of VROT. This will extend the life cycle of the substation and its 10(20)/0.42kV transformers.
- Consumer protection from break in neutral conductor.
- Protection reaction when a single phase short circuit is formed at the same time as a break in the neutral conductor.
- Significant voltage improvement to consumers as a result of reduction in voltage drops within main conductors in the grid.
- Significant grid intermittence improvement
- Faster delivery of electrical energy to consumers, faster finishing technology process and smaller 15-minutes peak power.
- Economically superior. Much lower capital investment in comparison with traditional methods of building new medium voltage grid and new substation.
- Significantly shorter construction period to resolve "grey zone" issues in comparison with traditional methods.
- No public hearings needed nor other permits as when doing it with traditional methods.
- Possible to use the existing grids for expansion to new consumer areas.
- Visually better solution in urban areas.
- Silent – no noise.
- Dry technology no environmentally hazardous materials.
- Fire retardant.
- Low to no maintenance.
- Simple method to determine locations for installation.
- Integral metering at VROT-18 simple monitoring of consumer usage in real time.

h. VROT-18-X Technical Characteristics:

Description	**Units**	**VROT-18-1**	**VROT-18-3**
Grid connection type		Single phase	Three phase
Primary Nominal Voltage	[V]	420 (438)	420 (438)
Secondary Nominal Voltage	[V]	230±10%	230±10%
Nominal Power	[kVA]	18	50
Frequency	[Hz]	50	50
Highest Voltage for equipment	[V]	1000	1000
Test Voltage 50Hz/1min	[V]	3000	3000
Impulse Voltage 1,2/50µs	[V]	5000	5000
Nominal Current	[A]	78	78/phase
Short Circuit Current Protection	[A]	63(80)	63(80)
No load protection	[V]	230±10%	230±10%
Working mode		MOD1/MOD2	MOD1/MOD2
Copper losses up to 75^{0}C	[W]	500	1200
Ferro losses	[W]	80	240
Power Factor, cos ϕ		0.97	0.97
Mechanical Protection		IP54	IP54
Temperature ambient	[^{0}C]	-40^{0}C to +60^{0}C	-40^{0}C to +60^{0}C
Equipment manufacturing type		dry technology	dry technology

Weight	[Kg]	95	285
Dimensions	[mm]	200x390x420	200x390x420
Pole mounting type		Strapped console	Triangular arrangement
Pole location type		Within grid lines	Within grid lines

i. <u>Real examples of field installed VROT-18-X within distribution grids:</u>

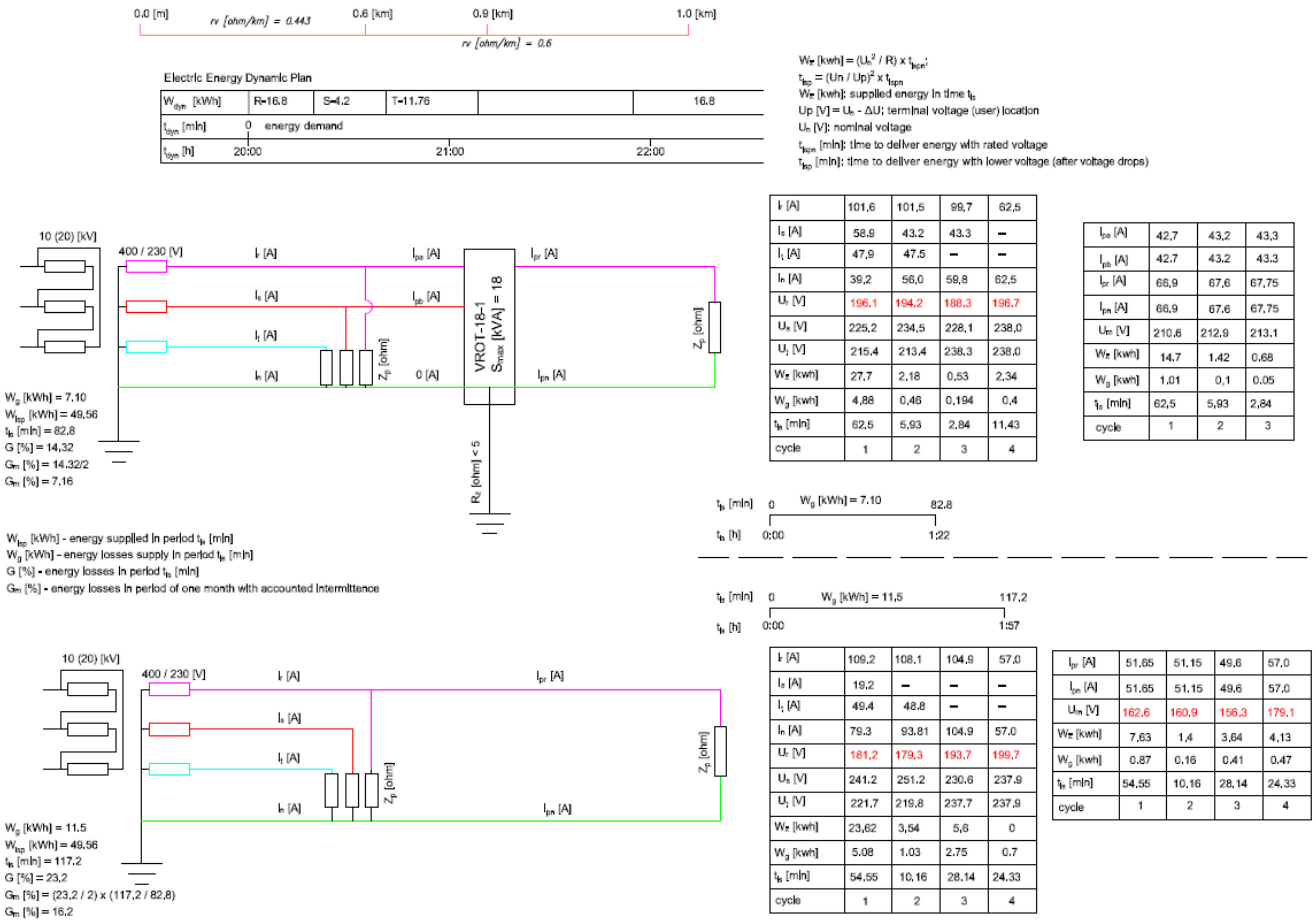
A. <u>Installation of VROT-8-1 in a low voltage distribution grid with the goal being to improve voltage level at the end of the grid.</u>

The field installation example below shows a way to resolve grey zones in rural areas. Analyses are done for the supply of energy to consumers per dynamic load plan measured between 20:00h and 22:00h. The consumer group being analyzed is 600m away from the substation and gets energy from phases R=16.8kWh, S=4.2kWh, T=11.76kWh, while the single phase consumer group at the end of this low voltage grid is getting 16.8kWh from phase R.

The measured values of currents and voltage are shown in tables in **Figure 7** for the events without VROT-18 and for the events with VROT-18. Voltage values at the end of the grid with VROT-18 are significantly improved, and measured losses are lowered from 11.05kWh to 7.1kWh. The time to supply the required electrical energy was improved from 1h:57min to 1h:22min within the considered dynamic interval.

The voltage and power quality at the consumer who is 600m away from the substation was previously not within the EN50160 standard. After installation of VROT-18-3 450m away from the substation, the power quality and voltage were corrected to satisfy the EN50160 standard.

<u>**Note: Increasing voltage within the substation does NOT solve these issues in this case.**</u>



Electric Energy Dynamic Plan

W_{dyn} [kWh]	R-16.8	S-4.2	T-11.76		16.8

t_{dyn} [min] 0 energy demand

t_{dyn} [h] 20:00 21:00 22:00

W_z [kwh] = $(U_n^2 / R) \times t_{lspn}$;
$t_{lsp} = (Un / Up)^2 \times t_{lspn}$
W_z [kwh]: supplied energy in time t_{ls}
Up [V] = $U_n - \Delta U$; terminal voltage (user) location
U_n [V]: nominal voltage
t_{lspn} [min]: time to deliver energy with rated voltage
t_{lsp} [min]: time to deliver energy with lower voltage (after voltage drops)

I_r [A]	101,6	101,5	99,7	62,5
I_s [A]	58.9	43.2	43.3	–
I_t [A]	47.9	47.5	–	–
I_n [A]	39,2	56,0	59,8	62,5
U_r [V]	196.1	194.2	188.3	196.7
U_s [V]	225,2	234,5	228,1	238,0
U_t [V]	215.4	213.4	238.3	238.0
W_z [kwh]	27,7	2,18	0,53	2,34
W_g [kwh]	4,88	0,46	0,194	0,4
t_{ls} [min]	62,5	5,93	2,84	11,43
cycle	1	2	3	4

I_{pa} [A]	42,7	43,2	43,3
I_{pb} [A]	42.7	43.2	43.3
I_{pr} [A]	66,9	67,6	67,75
I_{pn} [A]	66,9	67,6	67,75
U_m [V]	210.6	212.9	213.1
W_z [kwh]	14.7	1.42	0.68
W_g [kwh]	1.01	0,1	0.05
t_{ls} [min]	62,5	5,93	2,84
cycle	1	2	3

W_g [kWh] = 7.10
W_{lsp} [kWh] = 49,56
t_{ls} [min] = 82,8
G [%] = 14,32
G_m [%] = 14.32/2
G_m [%] = 7.16

t_{ls} [min] 0 W_g [kWh] = 7.10 82.8
t_{ls} [h] 0:00 1:22

W_{lsp} [kWh] - energy supplied in period t_{ls} [min]
W_g [kWh] – energy losses supply in period t_{ls} [min]
G [%] - energy losses in period t_{ls} [min]
G_m [%] - energy losses in period of one month with accounted intermittence

t_{ls} [min] 0 W_g [kWh] = 11,5 117,2
t_{ls} [h] 0:00 1:57

I_r [A]	109,2	108,1	104,9	57,0
I_s [A]	19.2	–	–	–
I_t [A]	49.4	48.8	–	–
I_n [A]	79.3	93.81	104.9	57.0
U_r [V]	181,2	179,3	193,7	199,7
U_s [V]	241.2	251.2	230.6	237.9
U_t [V]	221,7	219,8	237,7	237,9
W_z [kwh]	23,62	3,54	5,6	0
W_g [kwh]	5.08	1.03	2.75	0.7
t_{ls} [min]	54.55	10.16	28.14	24.33
cycle	1	2	3	4

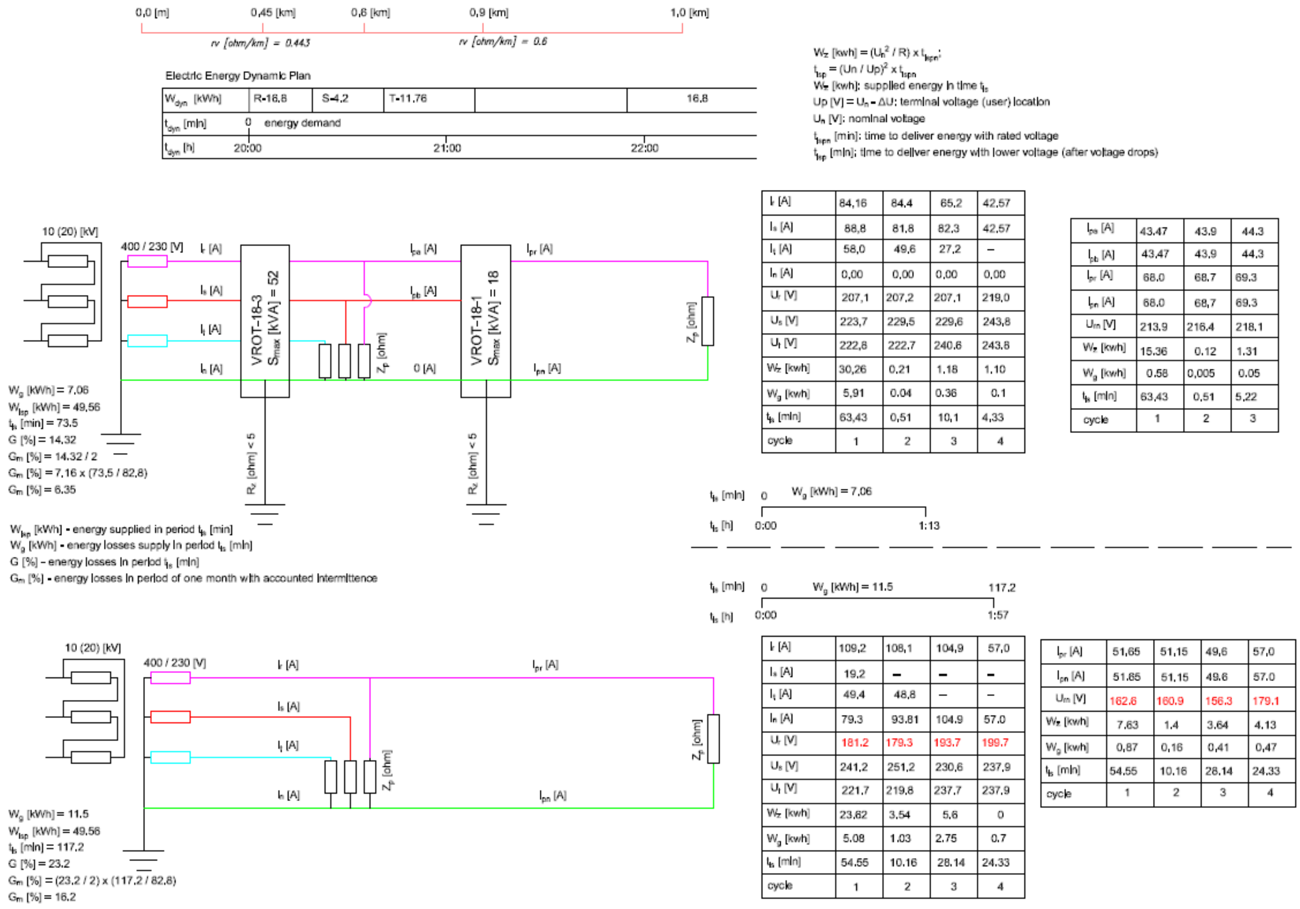
I_{pr} [A]	51,65	51,15	49,6	57,0
I_{pn} [A]	51,65	51,15	49,6	57,0
U_m [V]	162,6	160,9	156,3	179,1
W_z [kwh]	7,63	1,4	3,64	4,13
W_g [kwh]	0.87	0.16	0.41	0.47
t_{ls} [min]	54,55	10,16	28,14	24,33
cycle	1	2	3	4

W_g [kWh] = 11.5
W_{lsp} [kWh] = 49,56
t_{ls} [min] = 117.2
G [%] = 23,2
G_m [%] = (23,2 / 2) x (117,2 / 82,8)
G_m [%] = 16.2

Figure 7: Improving voltage levels

B. Installation of VROT-8-3 in combination with VROT-18-1 in low voltage distribution grid with the goal of resolving grey zones and intermittence.

A field example, presented in **Figure 8**, shows the elimination of all grey zones by combining VROT-18-3 and VROT-18-1 within that low voltage grid as per the recorded dynamic energy supply plan for time interval from 20:00h to 22:00h. At the same time, we are improving system intermittence as the time to supply the required energy with VROT-18-3 and VROT-18-1 installed is 1h:13min. It is noted that currents (loads) per phase are better distributed when VROT-18-3 and VROT-18-1 are installed than without them. Based on required electrical energy supplying time and losses within the analysed interval we can estimate monthly losses of electrical energy with VROT-18-3 and VROT-18-1 to be 6.35% versus without them to be 16.2%. See **Figure 8**.



I_r [A]	84,16	84,4	65,2	42,57
I_s [A]	88,8	81,8	82,3	42,57
I_t [A]	58,0	49,6	27,2	–
I_n [A]	0,00	0,00	0,00	0,00
U_r [V]	207,1	207,2	207,1	219,0
U_s [V]	223,7	229,5	229,6	243,8
U_t [V]	222,8	222.7	240.6	243.8
W_z [kwh]	30,26	0,21	1.18	1.10
W_g [kwh]	5,91	0.04	0.36	0.1
t_{ls} [min]	63,43	0,51	10,1	4,33
cycle	1	2	3	4

I_{pa} [A]	43.47	43.9	44.3
I_{pb} [A]	43.47	43.9	44.3
I_{pr} [A]	68.0	68.7	69.3
I_{pn} [A]	68.0	68,7	69.3
U_m [V]	213.9	216.4	218.1
W_z [kwh]	15.36	0.12	1.31
W_g [kwh]	0.58	0,005	0.05
t_{ls} [min]	63,43	0,51	5,22
cycle	1	2	3

I_r [A]	109,2	108,1	104,9	57,0
I_s [A]	19,2	–	–	–
I_t [A]	49,4	48,8	–	–
I_n [A]	79.3	93.81	104.9	57.0
U_r [V]	181.2	179.3	193.7	199.7
U_s [V]	241,2	251,2	230,6	237,9
U_t [V]	221,7	219,8	237,7	237,9
W_z [kwh]	23,62	3,54	5,6	0
W_g [kwh]	5.08	1.03	2.75	0.7
t_{ls} [min]	54.55	10.16	28.14	24.33
cycle	1	2	3	4

I_{pr} [A]	51,65	51,15	49,6	57,0
I_{pn} [A]	51.65	51,15	49.6	57.0
U_m [V]	162.6	160.9	156.3	179.1
W_z [kwh]	7,63	1.4	3.64	4.13
W_g [kwh]	0,87	0,16	0,41	0,47
t_{ls} [min]	54.55	10.16	28.14	24.33
cycle	1	2	3	4

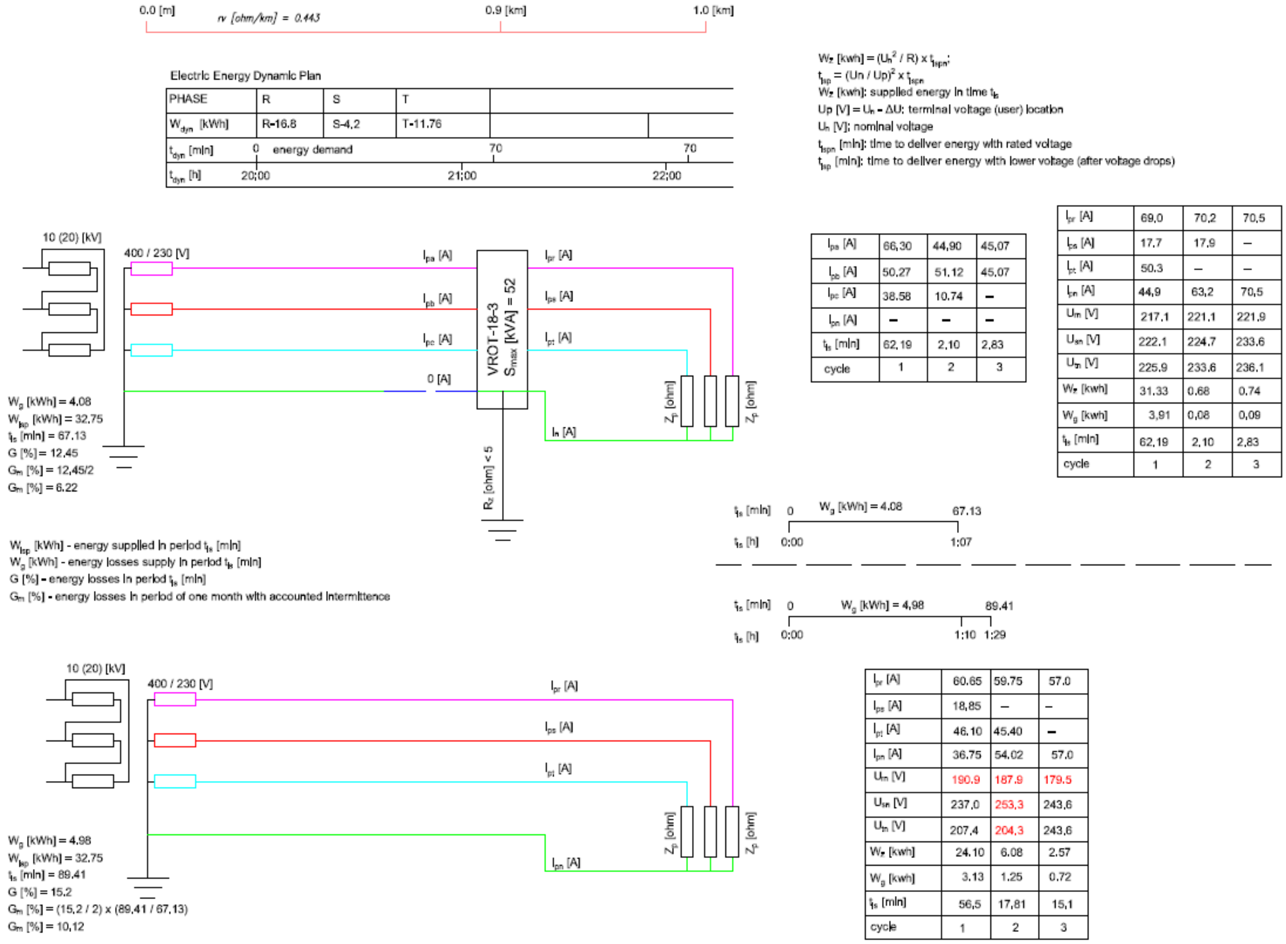
Figure 8: Grey zones and intermittence solution

C. <u>VROT-18-3 installation within low voltage line as a solution for grey zones</u>

The field example, presented in **Figure 9**, shows a consumer group 1000m away from the substation with low voltage levels. To eliminate all grey zones in that specific grid and that consumer group, a prior solution was applied by switching to SKS X00-Y 3x70+71.5mm^2 conduits directly from the substation. It was assumed that installing SKS (larger cross section) conduits between the substation and consumer group and redistributing loads would solve the low voltage issues at that location. No significant results were achieved, and the voltage level at that consumer group did not improve. After measuring the voltages for the dynamic energy supply plan between 17:00h and 19:00h it was determined that voltages still do not satisfy the EN50160 standard.

Installing VROT-18-3 lasted about 2 hours and right after executing this solution, new measurements showed that voltage levels were within the EN50160 standard. Electrical energy losses within the observed time interval were 4.08kWh with VROT-18-3 installed and 4.98kWh without. The time to supply that energy with VROT-18-3 was 1h:07min and without VROT-18-3 was 1h:29min. Based on the required energy supply, delay time and energy losses, total estimated losses within one month with VROT-18-3 are 6.22% and without VROT-18-3 are 10.12%.

<u>In real conditions actual losses with VROT-18-3 are 6.20% and without VROT-18-3 are 13.6%.</u>



Electric Energy Dynamic Plan

PHASE	R	S	T
W_{dyn} [kWh]	R-16.8	S-4,2	T-11.76

W_z [kwh] = $(U_n^2 / R) \times t_{ispn}$;
$t_{isp} = (Un / Up)^2 \times t_{ispn}$
W_z [kwh]: supplied energy in time t_{is}
Up [V] = $U_n - \Delta U$: terminal voltage (user) location
U_n [V]: nominal voltage
t_{ispn} [min]: time to deliver energy with rated voltage
t_{isp} [min]: time to deliver energy with lower voltage (after voltage drops)

I_{pa} [A]	66,30	44,90	45,07
I_{pb} [A]	50,27	51,12	45,07
I_{pc} [A]	38,58	10,74	–
I_{pn} [A]	–	–	–
t_{is} [min]	62,19	2,10	2,83
cycle	1	2	3

I_{pr} [A]	69,0	70,2	70,5
I_{ps} [A]	17.7	17,9	–
I_{pt} [A]	50.3	–	–
I_{pn} [A]	44,9	63,2	70,5
U_{rn} [V]	217.1	221.1	221,9
U_{sn} [V]	222.1	224.7	233.6
U_{tn} [V]	225.9	233.6	236.1
W_z [kwh]	31.33	0.68	0.74
W_g [kwh]	3,91	0,08	0,09
t_{is} [min]	62,19	2,10	2,83
cycle	1	2	3

W_g [kWh] = 4.08
W_{isp} [kWh] = 32,75
t_{is} [min] = 67.13
G [%] = 12,45
G_m [%] = 12,45/2
G_m [%] = 6.22

W_{isp} [kWh] - energy supplied in period t_{is} [min]
W_g [kWh] - energy losses supply in period t_{is} [min]
G [%] - energy losses in period t_{is} [min]
G_m [%] - energy losses in period of one month with accounted intermittence

W_g [kWh] = 4.98
W_{isp} [kWh] = 32,75
t_{is} [min] = 89.41
G [%] = 15.2
G_m [%] = (15,2 / 2) x (89,41 / 67,13)
G_m [%] = 10,12

I_{pr} [A]	60.65	59.75	57.0
I_{ps} [A]	18,85	–	–
I_{pt} [A]	46.10	45.40	–
I_{pn} [A]	36.75	54.02	57.0
U_{rn} [V]	190.9	187.9	179.5
U_{sn} [V]	237,0	253,3	243,6
U_{tn} [V]	207,4	204,3	243,6
W_z [kwh]	24.10	6.08	2.57
W_g [kwh]	3.13	1.25	0.72
t_{is} [min]	56,5	17,81	15,1
cycle	1	2	3

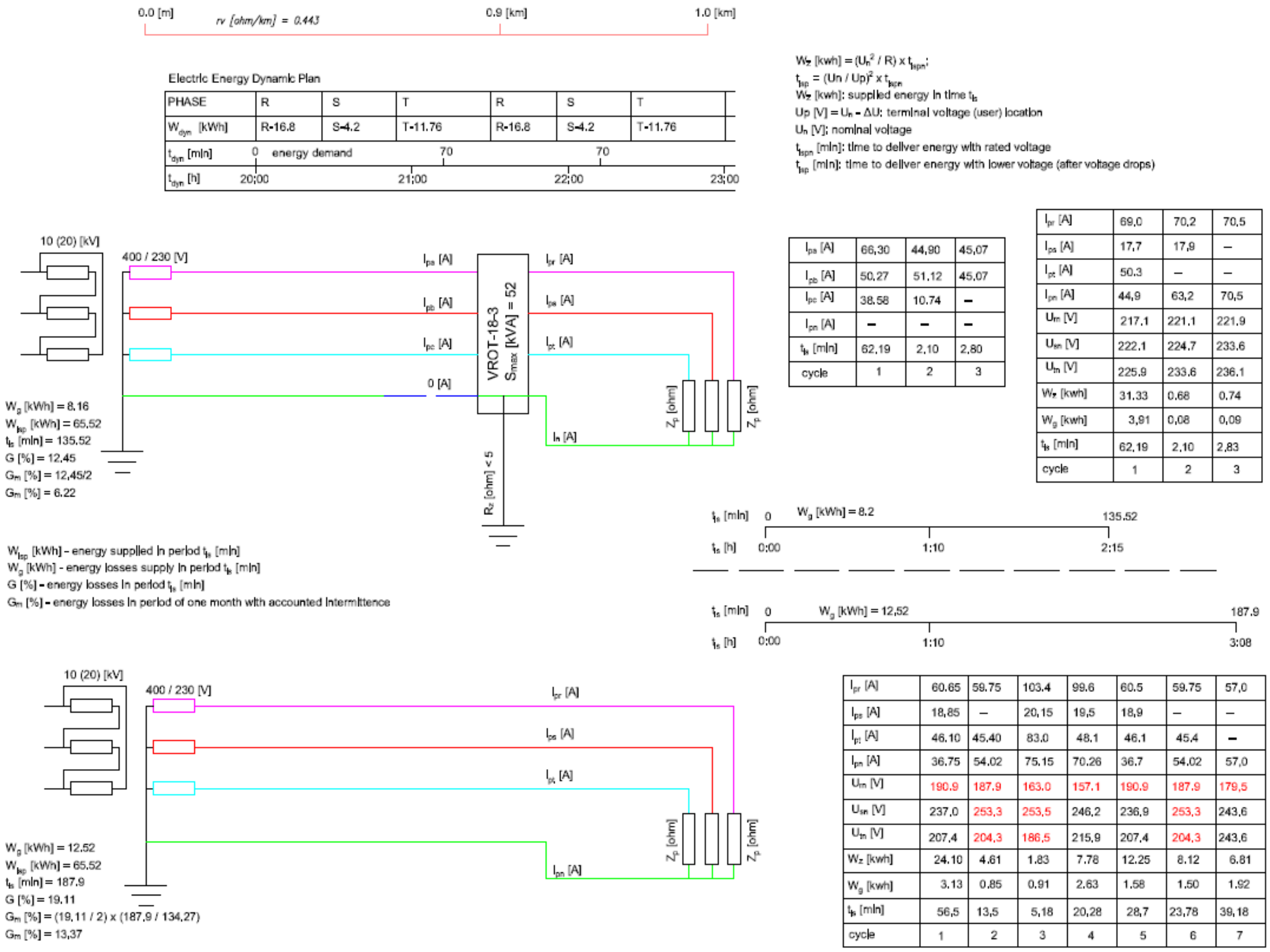
Figure 9: Solution with VROT-18-3 for grey zones

D. Supply of electrical energy by using VROT-18-3

The consumer group (**Figure 10**) supplied through VROT-18-3 is located at the end of a low voltage distribution grid. We looked at the dynamic energy supply process for the period of time between 20:00h and 23:00h. We can see that the energy demand from the consumers starting at 20:00h was R= 16.8kWh, S=4.2kWh, T=11.76kWh per phase.

After 70 minutes, at 21:10h, the same consumers demand that the electrical energy per phase is continuous as before R= 16.8kWh, S=4.2kWh, T=11.76kWh. With integration of VROT-18-3, the required energy was supplied within 2h:15min, energy losses were 8.2kWh and voltage levels were within the EN50160 standard. Prior to VROT-18-3 installation this required energy was supplied in 3h:08min, energy losses were 12.52kWh (**Figure 10**) and the voltage level was outside the EN50160 standard.

Based on these field measurements, applying VROT-18-3 system we generated a savings of 4.32kWh in only 3 hours.



Electric Energy Dynamic Plan

PHASE	R	S	T	R	S	T
W_{dyn} [kWh]	R-16.8	S-4.2	T-11.76	R-16.8	S-4.2	T-11.76

t_{dyn} [min] 0 energy demand 70 70

t_{dyn} [h] 20;00 21;00 22;00 23;00

W_z [kwh] = $(U_n^2 / R) \times t_{lspn}$;
$t_{lsp} = (Un / Up)^2 \times t_{lspn}$
W_z [kwh]: supplied energy in time t_{ls}
Up [V] = $U_n - \Delta U$: terminal voltage (user) location
U_n [V]: nominal voltage
t_{lspn} [min]: time to deliver energy with rated voltage
t_{lsp} [min]: time to deliver energy with lower voltage (after voltage drops)

I_{pa} [A]	66,30	44,90	45,07
I_{pb} [A]	50,27	51,12	45,07
I_{pc} [A]	38.58	10.74	–
I_{pn} [A]	–	–	–
t_{ls} [min]	62,19	2,10	2,80
cycle	1	2	3

I_{pr} [A]	69,0	70,2	70,5
I_{ps} [A]	17,7	17,9	–
I_{pt} [A]	50.3	–	–
I_{pn} [A]	44,9	63,2	70,5
U_{rn} [V]	217.1	221.1	221.9
U_{sn} [V]	222.1	224.7	233.6
U_{tn} [V]	225.9	233.6	236.1
W_z [kwh]	31.33	0.68	0.74
W_g [kwh]	3,91	0,08	0,09
t_{ls} [min]	62,19	2,10	2,83
cycle	1	2	3

W_g [kWh] = 8.16
W_{lsp} [kWh] = 65.52
t_{ls} [min] = 135.52
G [%] = 12.45
G_m [%] = 12,45/2
G_m [%] = 6.22

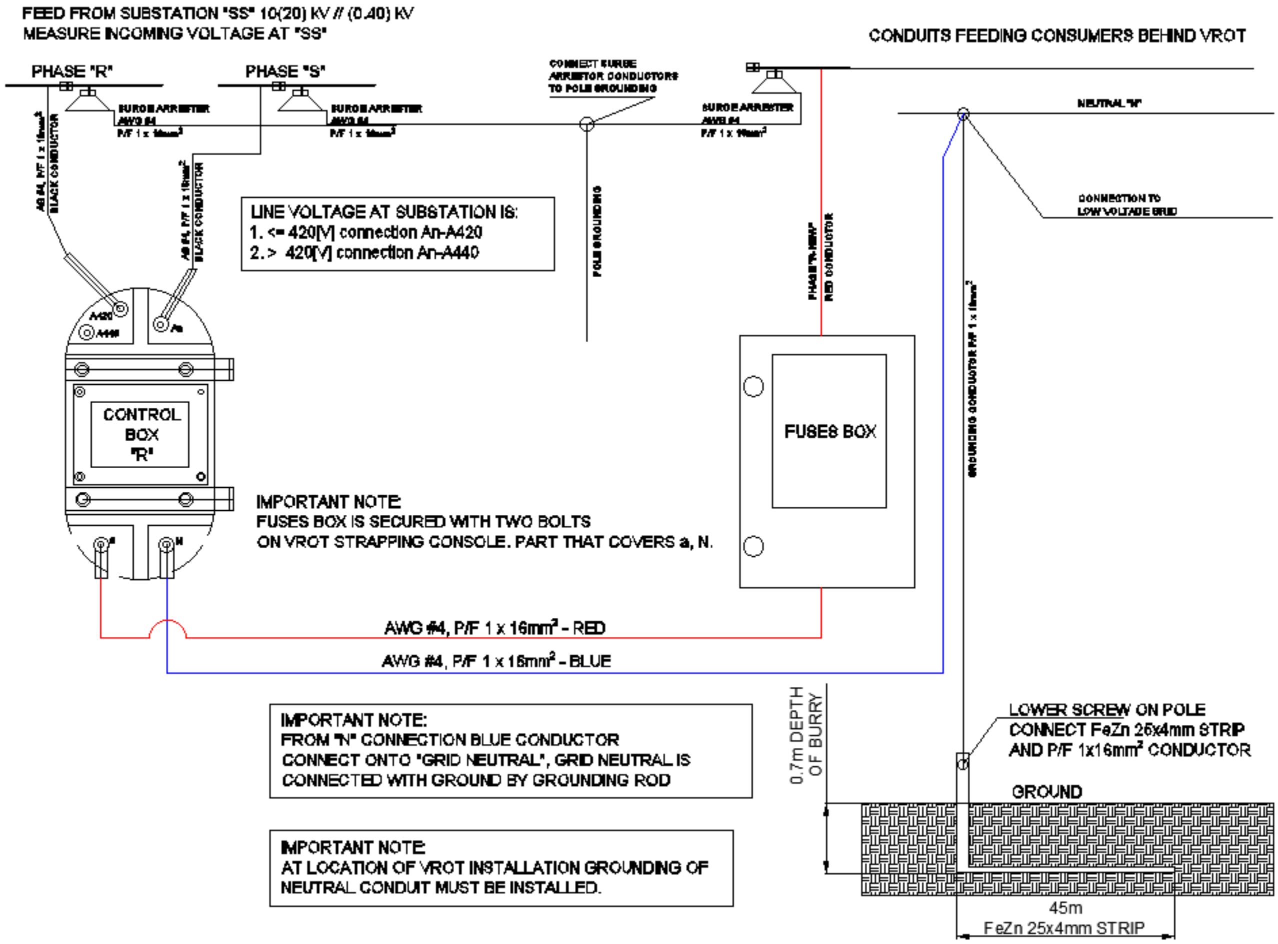
W_{lsp} [kWh] – energy supplied in period t_{ls} [min]
W_g [kWh] - energy losses supply in period t_{ls} [min]
G [%] – energy losses in period t_{ls} [min]
G_m [%] – energy losses in period of one month with accounted intermittence

W_g [kWh] = 12.52
W_{lsp} [kWh] = 65.52
t_{ls} [min] = 187.9
G [%] = 19.11
G_m [%] = (19,11 / 2) x (187,9 / 134,27)
G_m [%] = 13,37

I_{pr} [A]	60.65	59.75	103.4	99.6	60.5	59.75	57,0
I_{ps} [A]	18,85	–	20,15	19,5	18,9	–	–
I_{pt} [A]	46.10	45.40	83.0	48.1	46.1	45.4	–
I_{pn} [A]	36.75	54.02	75.15	70.26	36.7	54.02	57,0
U_{rn} [V]	190.9	187.9	163.0	157.1	190.9	187.9	179,5
U_{sn} [V]	237,0	253,3	253,5	246,2	236,9	253,3	243,6
U_{tn} [V]	207,4	204,3	186,5	215,9	207,4	204,3	243,6
W_z [kwh]	24.10	4.61	1.83	7.78	12.25	8.12	6.81
W_g [kwh]	3.13	0.85	0.91	2.63	1.58	1.50	1.92
t_{ls} [min]	56,5	13,5	5,18	20,28	28,7	23,78	39,18
cycle	1	2	3	4	5	6	7

Figure 10: Energy supply through VROT-18-3

2. INSTRUCTIONS FOR VROT-18-1 INSTALLATION



LINE VOLTAGE AT SUBSTATION IS:
1. <= 420[V] connection An-A420
2. > 420[V] connection An-A440

IMPORTANT NOTE:
FUSES BOX IS SECURED WITH TWO BOLTS
ON VROT STRAPPING CONSOLE. PART THAT COVERS a, N.

IMPORTANT NOTE:
FROM "N" CONNECTION BLUE CONDUCTOR
CONNECT ONTO "GRID NEUTRAL", GRID NEUTRAL IS
CONNECTED WITH GROUND BY GROUNDING ROD

IMPORTANT NOTE:
AT LOCATION OF VROT INSTALLATION GROUNDING OF
NEUTRAL CONDUIT MUST BE INSTALLED.

Figure 11: VROT-18-1 installation

3. INSTRUCTIONS FOR VROT-18-3 INSTALLATION

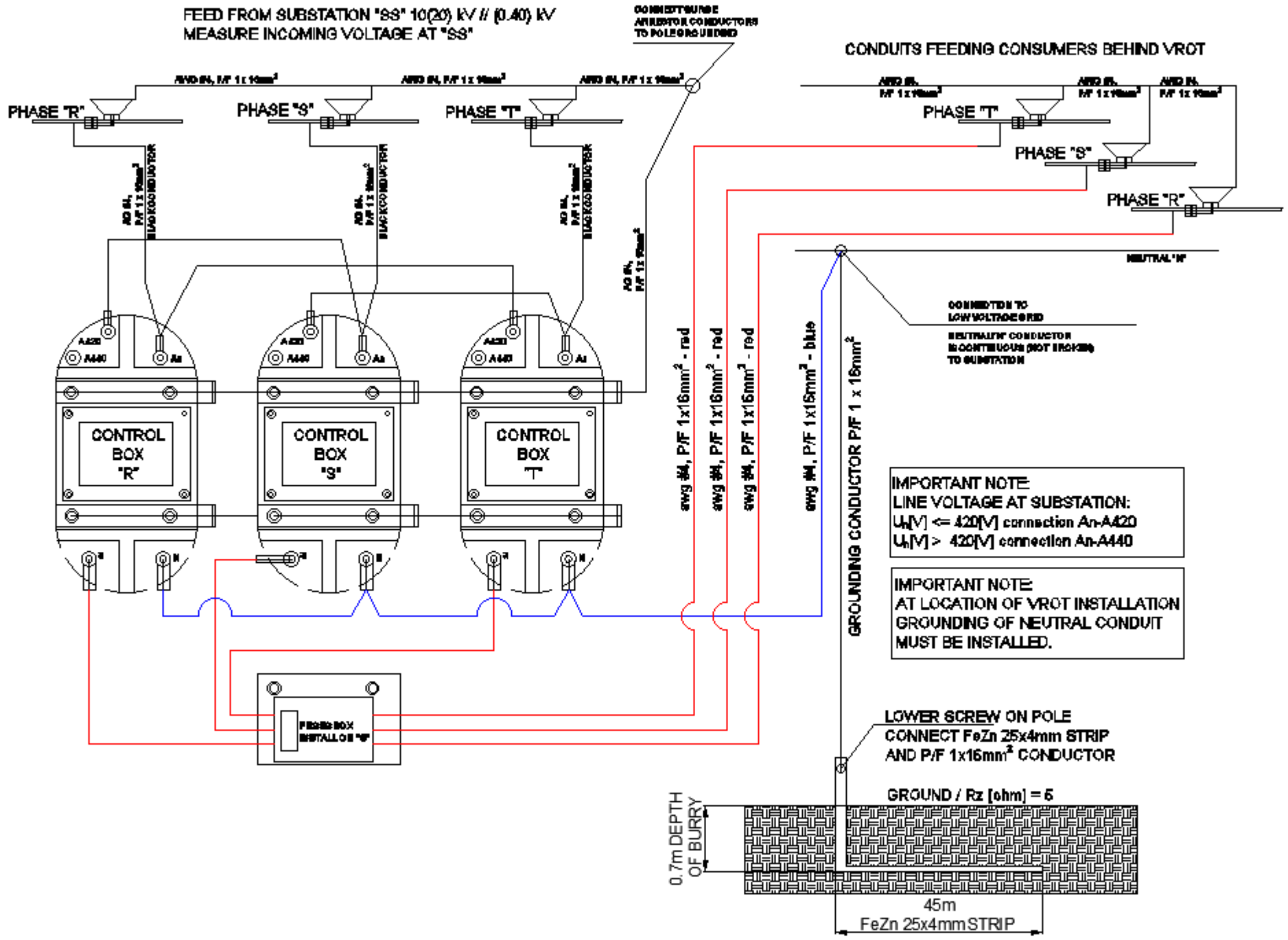
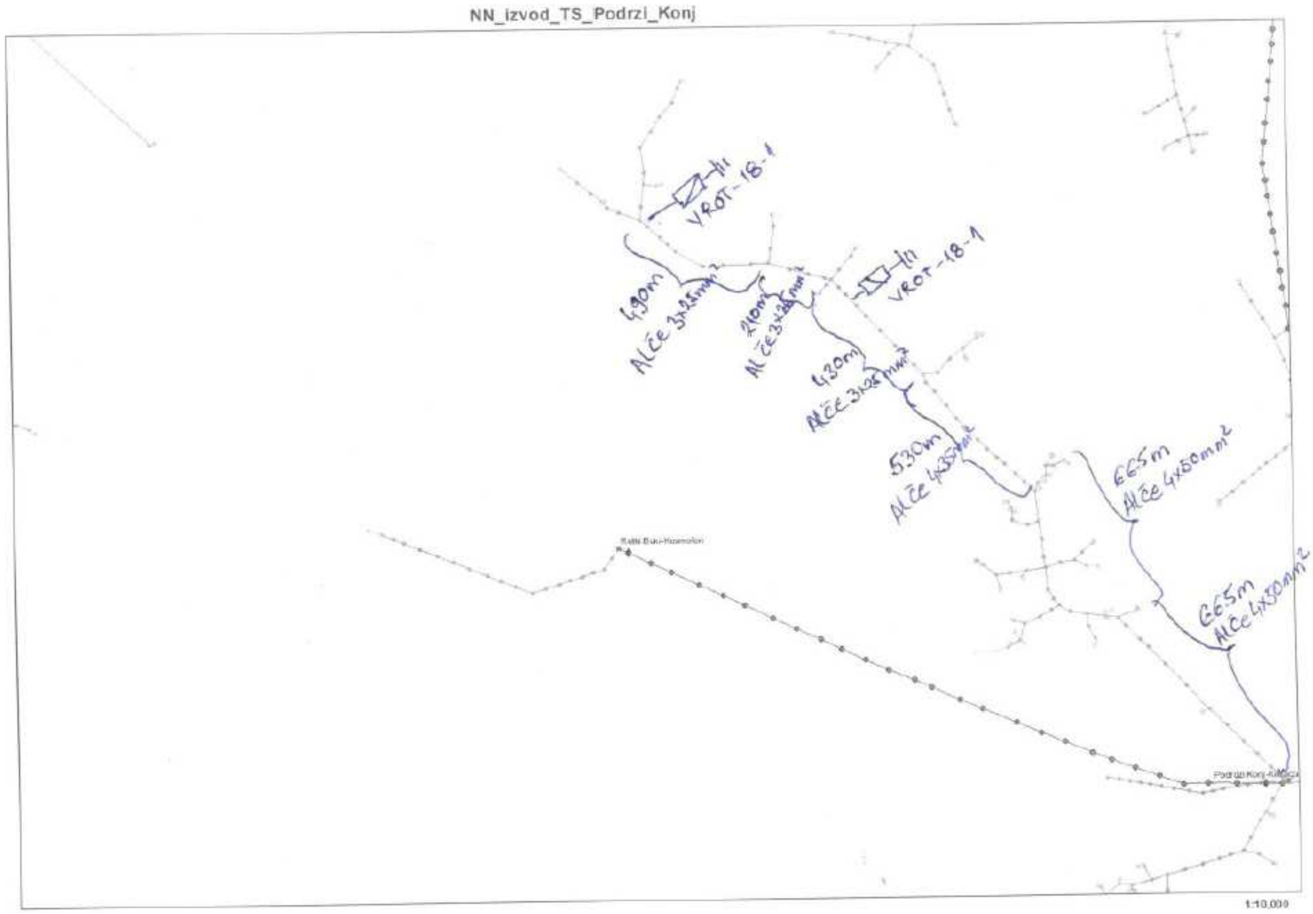
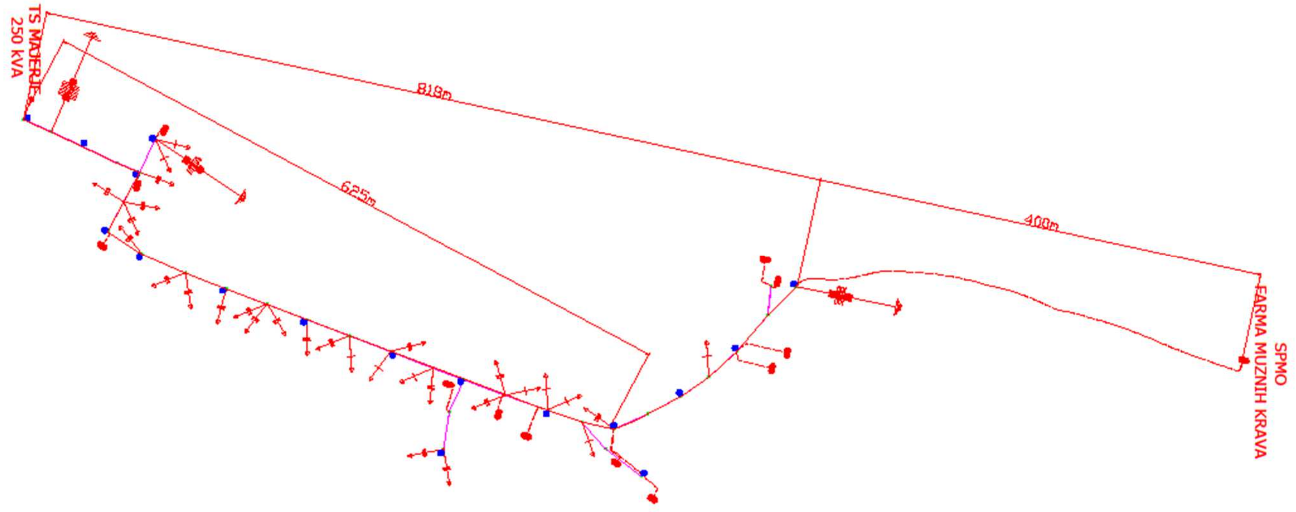


Figure 12: VROT-18-3 installation

4. MAP SHOWING SOLUTION FOR VOLTAGE LEVELS USING VROT-18-1



5. MAP SHOWING SOLUTION FOR VOLTAGE LEVELS USING VROT-18-3



6. FIELD INSTALLATION PHOTOGRAPHS OF VROT-18-1

Installation place for VROT-18-1 within low voltage distribution grid from substation output.

Rural municipality area supplied energy through VROT-18-1

Lifting VROT-18-1 onto the pole

Mounting VROT-18-1 onto the pole

VROT-18-1 mounted on the pole

Lightning overvoltage destroyed surge arrestor and VROT-18-1 not damaged at all

7. FIELD INSTALLATION PHOTOGRAPHS OF VROT-18-3

Installing console for VROT-18-3

Lifting VROT-18-3 onto the pole

Accepting VROT-18-3 on the pole

VROT-18-3 Installed on the pole

8. CONTACTS

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