CIGRE-299

2020 CIGRE Canada Conference
Toronto, Ontario, October 19-22, 2020

Manitoba Hydro Estella Substation, MVROT Pilot Project for the Energy Efficiency and Reduction of Losses in Electrical Power Distribution Grids "The MVROT Project"

A. Lemez, - Energo-Group d.o.o., Sarajevo, Bosnia and Herzegovina
D. Lemez, - Energo Group Canada Inc., Calgary, AB - Canada

SUMMARY

According to the Canadian Electricity Association and Infrastructure [5], several factors drive the need for large-scale investment in electricity infrastructure expansion, modernization, refurbishment, and innovation. As the condition of the existing essential infrastructures continues to deteriorate and loads continue to grow, power quality, transmission efficiency, distribution efficiency, power losses, grid reliability, GHG, public safety and cyber security become more of a concern for both utilities and industrial and residential consumers.

The Project goal was to address above issues, validate in the live dynamic grid environment, new innovative, energy efficiency, patented Method and System[1] and Medium Voltage Regulating and Optimizing Terminal (MVROT)[2] technology to reduce energy losses, demonstrate how it will increase efficiency of the existing distribution infrastructures, balance loads, and improve reliability and safety with minimizing capital investments. This Technical Paper presents the findings and results for the successfully executed Pilot Project in Winnipeg, Manitoba Hydro, Estella Substation grid.

Based on these recorded dynamic data (Refer to Sections 3., 3.1, 4. & 4.1) the MVROT Pilot Project demonstrated several key benefits to Utilities and its customers:

1) An average **increased feeder energy efficiency between 8.2% and 8.7%**.

2) **Improved phase voltage levels (~ 4.45%)** at load side of MVROT.

3) Reduced **overall amperage in system neutral line at substation between 29% and 39%.** Maximum amperage in neutral line before MVROT was 94[A] and with MVROT 68[A].

4) **Load balanced between phase A and B** as phase C was not utilized at all with this Project.

KEYWORDS

Efficiency, Economical solution for Distribution, Safety, Reduction of power losses and voltage drops, Innovative technology, Grid selectivity, Reduced power outages, Automatization, Load balance.

A. Lemez: energo.group@teol.net
D. Lemez: dlmain@egcanada.ca

1. INTRODUCTION

The Estella Substation MVROT Pilot Project was initiated between Manitoba Hydro (MH) and Energo Group Canada (EGC) at the 2017 Cigré Conference in Winnipeg, followed by EGC published White Paper “CIGRÉ - W2.07 – Abs 12” [3] at Cigré conference 2018 in Calgary and Project execution by MH and EGC in the field in Winnipeg at the end of 2019 and beginning of 2020.

This Pilot Project improved balancing of phase loads in Manitoba Hydro’s, Estella station in Winnipeg, within one of its medium voltage (4.16kV) distribution feeders, by installing one MVROT[2], CSA certified[4]. The Pilot Project successfully demonstrated, the simple and cost-effective innovative and patented Method and System[1] to reduce losses, balance loads and increase feeder energy efficiencies. MVROT improved power quality and voltage levels at the load side far away from substation, reduced loads in neutral line, increased reliability and resiliency and added grid selectivity.

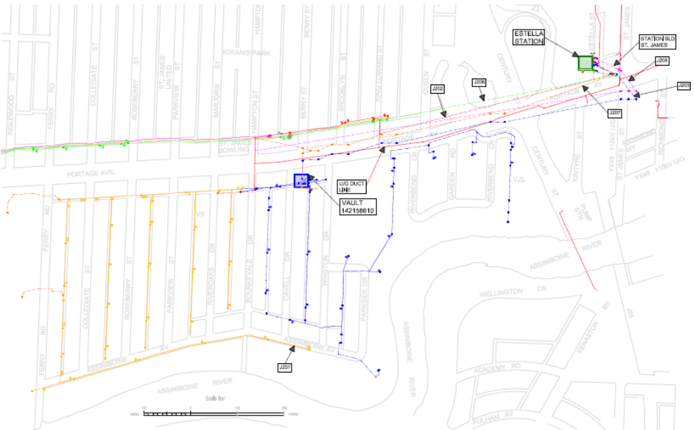


Figure 1

“Figure 1” shows the Estella grid with all outgoing distribution feeders going towards the residential areas. The J207 feeder (orange lines) was found to be most suitable for installing the MVROT into one of its branches. Baseline data was recorded for one week prior to MVROT being energized and one week after MVROT was energized. These two weeks of recorded readings would be comparable with similar dynamic loads. MVROT was installed in the J207 branch at the intersection between Ferry RD and Assiniboine AV, approximately 2km away from Estella Substation.

The installation site location was finalized based on grid layout, distances from the substation, maximum loads in the branch and nominal load (185kVA) for one MVROT.

The Pilot Project’s objective was to compare all recorded data and results before and after MVROT implementation as per EN 50160 standard, proving power quality improvements within the existing selected feeder.

2. FIELD PROGRAM

Picture-1 lifting MVROT on 50’ tall pole

To implement MVROT installation, MH was required to install three new poles (one 50’ tall and two 45’ tall, one on each side of the new 50’ pole). This was done to evenly transition O/H lines in the vertical plane and to eliminate possible line tension as the existing poles are 40’ tall. To install MVROT on the pole: one 50’, Class 2 pole, was selected. This was to satisfy MH standards for the equipment spacing and supporting equipment weights, MVROT alone weighs some 870kg. Together with MVROT, one ABB line voltage instrument transformer was installed on the same 50’ pole. (See Picture-1)

The phase branch was connected to phase “B” from the three phase feeder at this location, and a second line, phase “A”, was brought up to the 50’ pole to be used when MVROT is energized. Aclara and Cooper sensors were mounted directly on the phases “A” and “B” (feeder side), and phase “B” (load side) close to the new 50’ pole. A Rogowski CT coil was installed around the system’s neutral line on the feeder side of

MVROT on the new 50’ pole. Its cables, along with the ABB instrument voltage transformer cables were brought into the metering cabinet where the HIOKI-3196 analyser was located to record all data these two instrument transformers were reading (line voltage and currents in neutral line). All readings were synchronized to be recorded in 15-minute intervals, 24h a day for seven days prior to MVROT being energized. The same recording procedure was done for another 7 days after MVROT is energized. Aclara and Cooper sensors were wirelessly connected to the MH distribution center where all recordings from Substation and Pilot Project site are recorded directly onto MH’s network server.

Total nominal loads in single phase “B” feeding Assiniboine Avenue residents is **162 kVA** spread over 590m and five (5) step down transformers 2.4kV//120V/240V: 50kVA, 25kVA, 37kVA, 25kVA and 25 kVA. By installing MVROT at this single-phase (Phase “B”) branch take-off, MVROT becomes the load source for these five SDTs. MVROT nominal rated power is 185kVA.

IMPORTANT NOTES:

a) Neutral line (LV) return amperage, from the five users getting power from the 50kVA (SDT), located at load side of MVROT, is connected to the main system neutral at feeder side of the MVROT. That local circuit amperage is always getting recorded by the Rogowski CT coil.

b) Due to large amount of collected data and many different analyses we did, please refer for more detailed analyses, calculations, and records to full Pilot Project Report [6].

c) All graphs in this Technical Paper are showing only first part, short time period. Please refer to full Pilot Project Report [6] for full graph of two times two weeks records.

2.1 RECORDED DATA, EQUIPMENT AND DATES

DATA RECORDED	EQUIPMENT USED	DATA COLLECTED
At Substation J207 feeder (With and Without MVROT): • Regulated Phase Voltages: APH, BPH, CPH, • Amperage: IA, IB, IC, IN **At MVROT location (Phase B branch - bypass):** • Phase output Voltage: BPH • Amperage: IA, IB, IN, Ia • Line Voltage: UAB	• Aclara Sensors at Substation For phase voltage and amperage • Aclara Sensors at MVROT location For phase voltage and amperage • Cooper sensors at MVROT location For amperage • HIOKI 3196 analyser at MVROT location • Rogowski CT at MVROT location • Voltage Instrument Transformer (ABB) at MVROT location • MVROT-250-4.16//2.4 (185kVA)	**Baseline Records (Without MVROT):** From Jan 02, 2020 to Jan 09, 2020 **Second Records with MVROT:** From Jan 28, 2020 to Feb 06, 2020 All records collected at 15min 24h/day

Pictures – 2 and 3, HIOKI metering cabinet on the same pole with MVROT

3. VOLTAGE ANALYSES FOR (Jan 2nd, 2020 to Feb 06th, 2020) [6]

- **Baseline:** Thursday, Jan 2nd, 2020 at 9:00 AM ends Thursday Jan 9th, 2020 at 7:45 AM
- **With MVROT:** Thursday Jan 30th, 2020 at 9:00 AM ends Thursday Feb 6th, 2020 at 7:45 AM

"**Figure 2a**" shows, Phase "B", phase voltage (2.4kV nominal) records in graphical form connected to three phase J207 feeder. All recorded data are aligned with weekdays, dates and times as per bullets above. Baseline phase voltage records at substation are shown with the red line and at the MVROT location with the cyan line. Once MVROT was energized the voltage improved (magenta line to green line). **Note: MVROT is NOT an autotransformer**

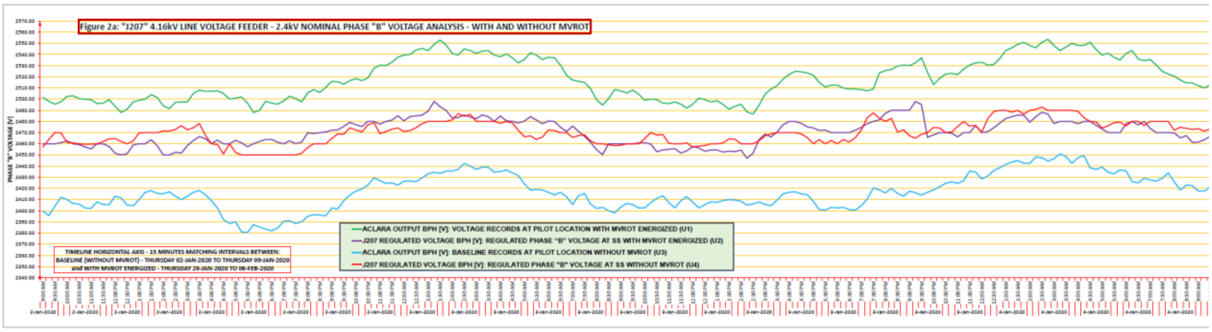


Figure 2a

"Figure 2b" shows the percentage of the overall improvement in phase "B" energy efficiency over 15-minute intervals with the trend line between 8.2% and 8.5%. Weekdays and daytimes aligned. Average energy efficiency is increased by 8.31%. Significant results are shown in **"Table 1"** below.

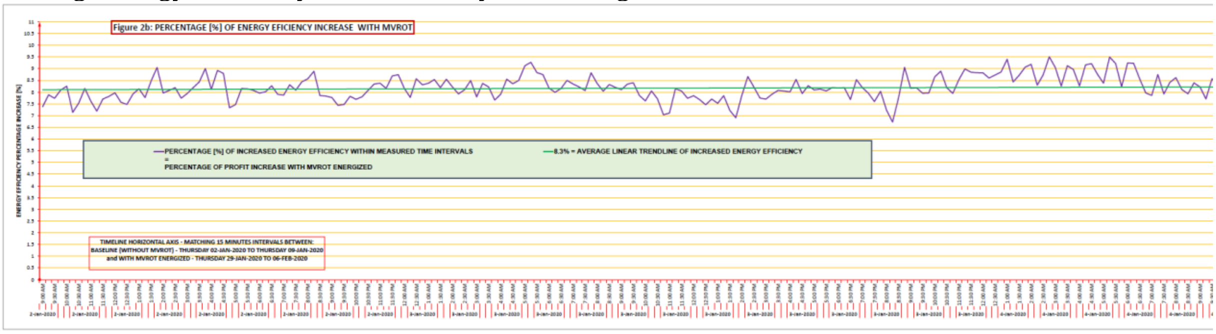


Figure 2b

Table 1: Significant records and results associated with Figure 2a and Figure 2b graphs:

PHASE / DATA	BASELINE	WITH MVROT	IMPROVEMENTS*
Maximum Phase Voltage [V]	**2451.5**	**2553.5**	**+102 [V] or (4.16%)**
Minimum Phase Voltage [V]	**2360.5**	**2481.0**	**+120.5 [V] or (5.10%)**
Maximum Low Voltage [V]	**122.58**	**127.68**	**+5.1 [V] or (4.16%)**
Minimum Low Voltage [V]	**118.03**	**124.05**	**+6.02 [V] or (5.10%)**
Max voltage [V] drop [-] / improved [+]	**-33.72**	**+146.50**	**-**
Min voltage [V] drop [-] / improved [+]	**-88.00**	**+53.50**	**-**
Min / Max Increased voltage % -With MVROT		**4.16% / 5.10%**	
Min / Max / Avrg. efficiency increased -With MVROT		**6.34% / 10.04% / 8.31%**	

**Positive values are voltage improvements within allowable limits*

As shown in "**Table 1**", Medium and Low Voltages values with MVROT are always higher than the nominal. Based on the analytical relationship $\Delta U_{[V]} = r_{[ohm/km]} * L_{[km]} * I_{[A]}$, voltage drop increases when loads increase. In this situation, to satisfy low voltage level standards, and to compensate voltage drops, when there is no MVROT in the system, Utility would need to reconstruct entire sections of the feeder lines by changing them for the larger cross section conductors (smaller resistivity $r_{[ohm/km]}$). **Adopting MVROT technology**, gives significant technical gain in stabilizing and improving voltage levels within standards for much wider spectrum of additional loads without needing to change the existing conductors. **This is a significant economical benefit to the Utilities**.

3.1 ENERGY EFFICIENCY ANALYSES AND CALCULATIONS [6]

Reducing voltage drops resulted in overall reduced time to deliver required energy and thus improved energy efficiency of this feeder. Grid Energy efficiency is a function of time $\mathbf{W_{[kWh]}=P_{[kW]}*t_{[h]}}$ and with MVROT energized it reduces the time to deliver required power, eliminates the bottleneck in delivering energy.

Based on the above, feeder energy efficiency increases along phase "B", shown in "**Figure 2b**" is expressed through the comparison of delivered amount of energy to the end users at the pilot project location with and without MVROT, and the amount of energy that would be delivered if voltage level is equal as at Substation = ideal condition.

Calculation of these delivered energy amounts is based on records and energy formula:

$\mathbf{W_{[kWh]} = P_{[kW]}*t_{[h]} = (U^2/R) * t;}$ **U = voltage, t = constant** (15min measuring intervals)

R = constant; representing total number of end users connected**.**

Recorded actual data:

- U_1 = BPH [V]: VOLTAGE RECORDS AT PILOT LOCATION WITH MVROT ENERGIZED
- U_2 = BPH [V]: REGULATED PHASE "B" VOLTAGE AT SS WITH MVROT ENERGIZED
- U_3 = BPH [V]: BASELINE VOLTAGE RECORDS AT PILOT LOCATION WITHOUT MVROT
- U_4 = BPH [V]: REGULATED PHASE "B" VOLTAGE AT SS WITHOUT MVROT

- **Table 2: Energy efficiency calculations**

With MVROT energized:	$\mathbf{W_1/W_2 = (U_1/U_2)^2}$ $\mathbf{W_1 = (U_1/U_2)^2 * W_2}$ $\mathbf{W_1 = k_1 * W_2}$	• W_1=delivered energy to the end users. • W_2=energy that would be delivered to the end users if voltage level at MVROT location is equal to Substation (Ideal conditions). • k_1=Voltage ratio "$(U_1/U_2)^2$"; Records are showing improved voltage in feeder which resulted in "k_1" voltage ratio > 1. • Reduced power losses and requires less time required to deliver demanded power.
Without MVROT energized:	$\mathbf{W_3/W_4 = (U_3/U_4)^2}$ $\mathbf{W_3 = (U_3/U_4)^2 * W_4}$ $\mathbf{W_3 = k_2 * W_4}$	• W_3 = delivered energy to the end users. • W_4 = energy that would be delivered to the end users if voltage level at MVROT location is equal to Substation (Ideal conditions). • k_2 = Voltage ratio "$(U_3/U_4)^2$"; The baseline records are showing voltage drops in feeder, resulting in "k_2" voltage ratio < 1. • Accrued power losses and requires more time to deliver demanded power.
Energy Efficiency	$\mathbf{E_f = (k_1-1) * 100 + (1-k_2) * 100}$	• Ef = Energy Efficiency Percentage change; (total percentage of voltage change)

As power is in direct relation to amperage and voltage, any voltage change will result in amperage change to deliver the same power. Improvement in voltage will reduce amperage and will reduce voltage drops and power losses. By improving voltage, we are improving intermittence (latencies) – time to deliver required power, and with that improving feeder energy efficiency.

Based on this and relations indicated in "**Table 2**" above, and the Pilot Project's recorded voltage data; Total voltage changes compared for the same time frame in a weekday, is a sum of these two voltage ratios ("k_1" and "k_2") converted into percentages. Absolute difference between them is total energy efficiency improvement in this feeder, increasing ability to deliver more energy within the same time frame.

INCREASED ENERGY EFFICIENCY [%] WITHIN MEASURED TIME INTERVALS

=

INCREASED PROFIT [%] WITH MVROT ENERGIZED

4. AMPERAGE ANALYSES (Jan 2nd, 2020 to Feb 06th, 2020) at Estella Substation [6]

- **Baseline:** Thursday, Jan 2nd, 2020 at 9:00 AM ends Thursday Jan 9th at 7:45 AM
- **With MVROT Records:** Thursday Jan 30th, 2020 at 9:00 AM ends Thursday Feb 6th, at 7:45 AM

"Figure 3a" shows baseline amperage (load) records at the substation within phase "A" (cyan line, maximum 164.14[A]), phase "B" (orange line, maximum 207.60[A]) and neutral line (green line). Phases "A" and "B" are somewhat aligned but the loads are visibly different. These unbalanced loads in combination with loads in phase "C", that was not address at all, produce some big amperages within neutral line (maximum 94.71[A]).

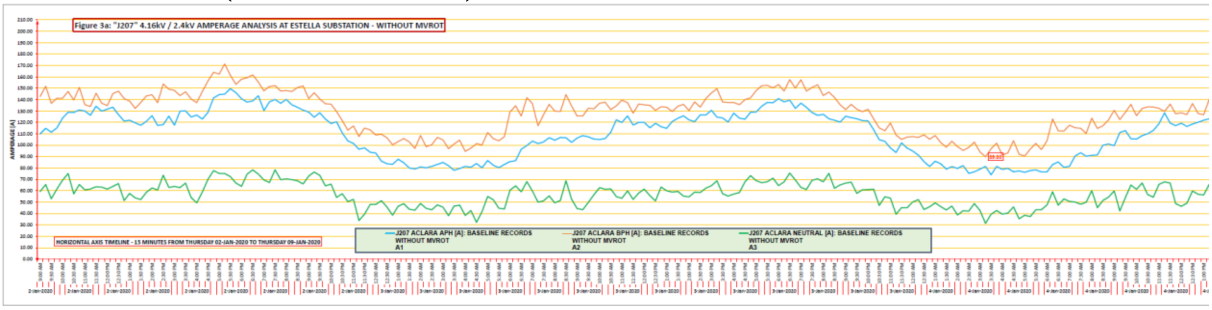


Figure 3a

"Figure 3b" shows the same records as "**Figure 3a**" but with MVROT energized. Phase "A" (dark red line, maximum 174.29[A]), phase "B" (blue line, maximum 173.24[A]) and neutral line (red line). Phases "A" and "B" are almost perfectly aligned, and their loads are in balance. These balanced loads, in combination with MVROT eliminating currents in the neutral conduit at its location, reflected significant reductions in amperages within the neutral line at substation (maximum 65.90[A]). Remaining loads in neutral at substation are mainly due to the unbalanced phase "C" that we did not address with this Pilot Project.

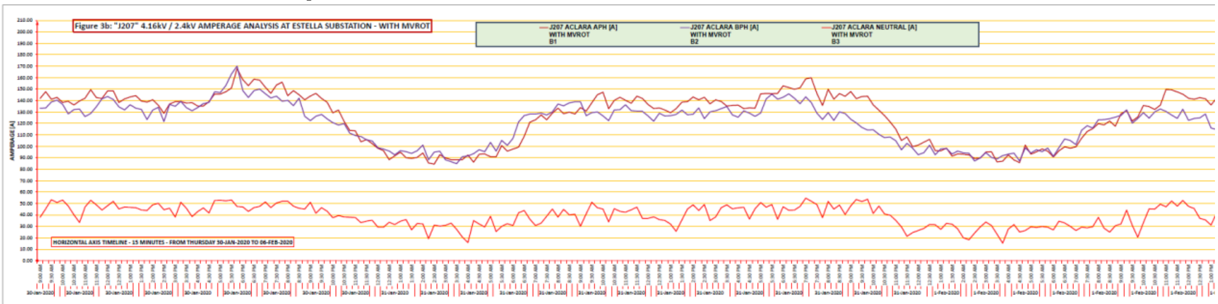


Figure 3b

"Figure 4a" only shows the differences between amperages (loads) within neutral conductor at substation. A significant and constant reduction of the currents in neutral conductor is clearly visible. The trend line shows a **reduction of 29% to 39%.**

Neutral amperage reduction percentage: **[%] = (A_3-B_3) / A_3*100**

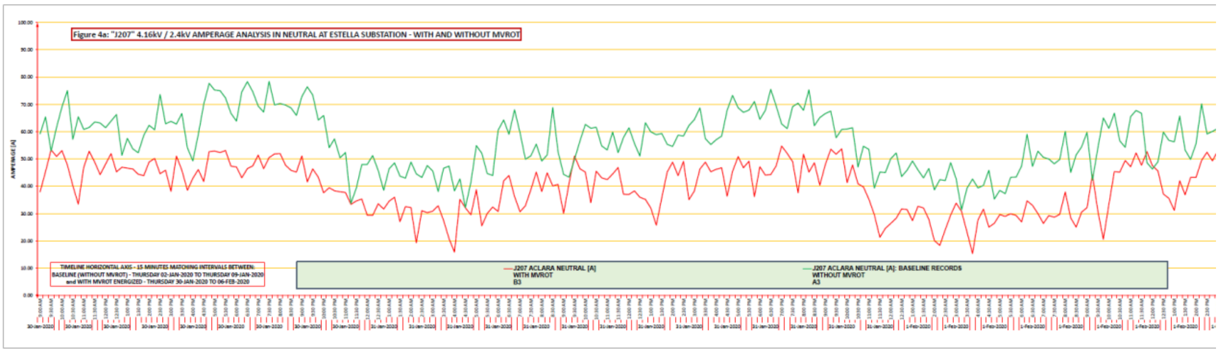


Figure 4a

Table 3: Significant records associated with graphs shown in Figures 3a through Figure 4a:

PHASE / DATA	BASELINE	WITH MVROT	IMPROVEMENTS*
Maximum Amperage Phase A [A]	164.14	174.29	10.15 [A]
Minimum Amperage Phase A [A]	73.41	83.31	9.9 [A]
Maximum Amperage Phase B [A]	207.60	173.24	-34.36 [A]
Minimum Amperage Phase B [A]	89.80	80.02	-9.78 [A]
Maximum Amperage Neutral [A]	94.71	65.90	-28.81 [A]
Minimum Amperage Neutral [A]	30.16	11.74	-18.42 [A]
Min / Max reduction in Neutral [A]	-	-4.04 / 52.7	-
Neutral load [%] reduction trendline	-	29% and 39%	-
Overall [%] of energy efficiency imp.	-	8.7%	-

**Positive values in IMPROVEMENTS column are amperage increase; negative values are amperage decrease achieved with MVROT energized. Negative values are representing phase/neutral line improvements.*

4.1 AMPERAGE ANALYSES (Jan 2nd to Feb 6th, 2020) at MVROT location [6]

- **Baseline:** Thursday, Jan 2nd, 2020 at 9:00 AM ends Thursday Jan 9th at 7:45 AM
- **With MVROT Records:** Thursday Jan 30th, 2020 at 9:00 AM ends Thursday Feb 6th at 7:45 AM

"Figure 5a" shows load in phases "A" and "B" connected at the primary side of MVROT completely balanced. Notice that both lines representing amperage in each phase are almost 100% identical. There are few minor differences that can be ignored as reading errors as they are less than 5[A]. Max / Min errors are: +3.20[A] / - 1.90[A].

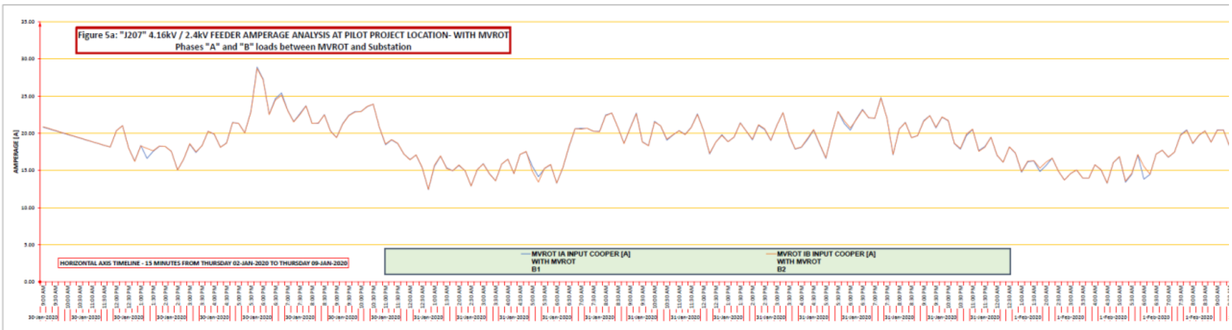


Figure 5a

"Figure 5b" shows amperage in MVROT secondary phase "a" feeding five SDT and amperage in neutral line from low voltage loads whose current circuit is connected to this system's neutral line. Multiplying the secondary amperages "B3" with constant transformation factor "0.6" resulted in getting amperages in phase "A" and phase "B" which match the Cooper sensors recorded values. Max / Min deviation between measured and calculated (expected primary amperage values) are negligible: +3.36[A] / -4.43[A] which is <5[A].

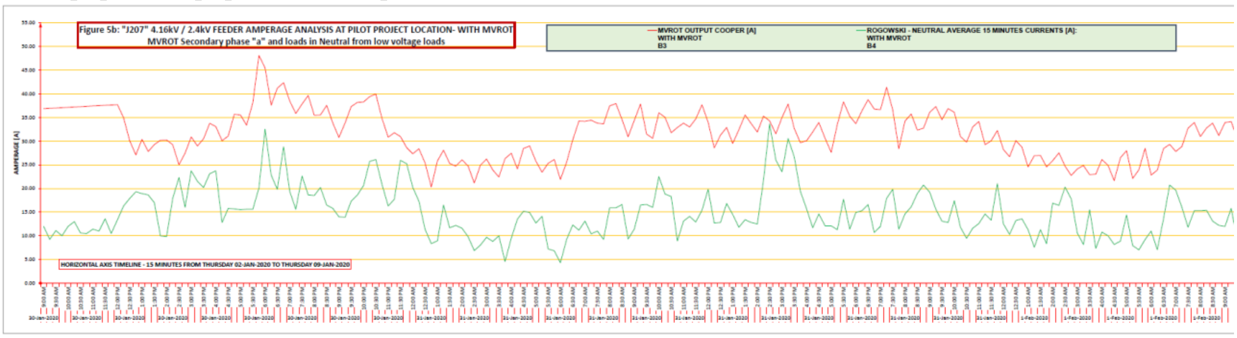


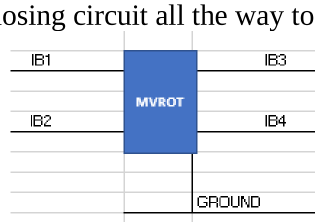
Figure 5b

To obtain power losses in the lines without and with MVROT energized, analyses were completed with the recorded amperages at MVROT location. Here is the summary and explanation of the analyses.

- I_{B1} = MVROT IA INPUT COOPER [A] WITH MVROT
- I_{B2} = MVROT IB INPUT COOPER [A] WITH MVROT
- I_{B3} = MVROT OUTPUT COOPER [A] WITH MVROT
- I_{B4} = ROGOWSKI - NEUTRAL AVERAGE 15 MINUTES CURRENTS [A] WITH MVROT

Without MVROT: Recorded amperages (**I_{B3}, I_{B4}**) are closing circuit all the way to the substation.
With MVROT energized: These amperages are transformed into **I_{B1}** and **I_{B2}** by MVROT, and **I_{B1}** and **I_{B2}** are closing circuit all the way to the substation instead.

Feeder / substation side



Load side

Schematics of line amperages at MVROT location

- **I_A:** $I_{B1} - I_{B3}$ (reduction of I_{B3} amperages that would go all the way to the substation)
- **I_B:** $I_{B2} – I_{B4}$ (reduction of I_{B4} amperages that would go all the way to the substation)

Total amperage changed through these two conductors is an addition of these two: **$I_A + I_B$**

__Losses in lines are:__ **$P_v = r_v * I^2$**

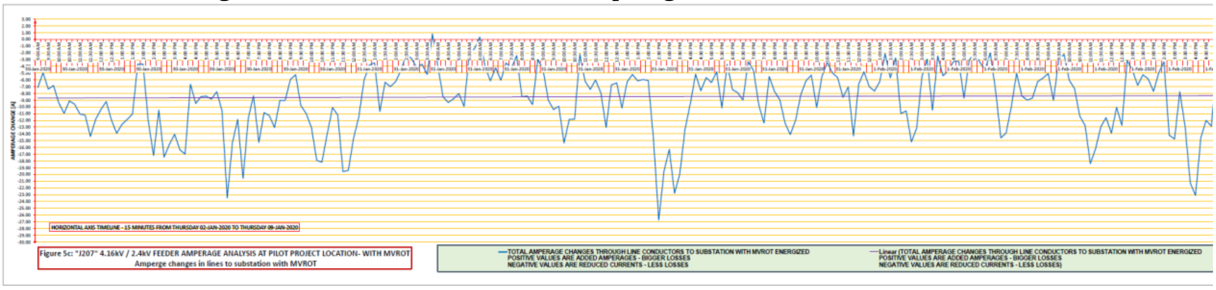
- Without MVROT: **$I_1^2 = I_{B3}^2 + I_{B4}^2$; $P_{v1} = r_v * I_1^2$**
- With MVROT: **$I_2^2 = I_{B1}^2 + I_{B2}^2$; $P_{v2} = r_v * I_2^2$**

Relationship between the losses in line without MVROT and with MVROT is: **$P_{v1} = K * P_{v2}$**

- P_{v1} - line losses without MVROT
- P_{v2} - line losses with MVROT

$K = P_{v1} / P_{v2} = (I_{B3}^2 + I_{B4}^2) / (I_{B1}^2 + I_{B2}^2) = I_1^2/ I_2^2$

"Figure 5c" shows the values of these amperage changes based on records of one week of data when MVROT was energized. The trendline shows an amperage reduction between -7.9 [A] and -8.9[A].

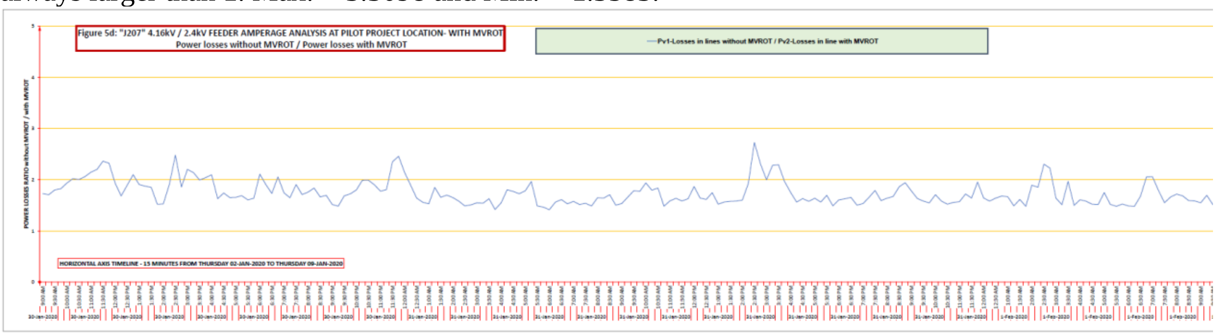


"Figure 5c

The analyses shown in **Figure 5c** has identified numbers of two major events:

- Number of events in one week that total amperage changes are greater with MVROT installed in this feeder: **7, with maximum increased losses of 0.82 [A]**
- Number of events in one week that total amperage changes are smaller with MVROT installed in this feeder: **661, with maximum reduced losses of -27.50 [A]**

"Figure 5d" shows these calculated power losses ratios. With the loss's ratio > 1, the feeder has larger losses without MVROT than with MVROT. For the whole monitoring time, these loss's ratios are always larger than 1. Max: = 3.3098 and Min: = 1.3583.



"Figure 5d

5. CONCLUSION

The MVROT[2] technology implemented during the Pilot Project in Estella substation grid in Winnipeg Manitoba at the beginning of 2020 demonstrates extremely successful records and results. The comparisons between the baseline records and records with MVROT energized show significant improvements in this feeder. To name several major ones:

> Improved Voltage, Amperages in phase lines reduced, Amperage in system neutral eliminated / reduced, Feeder Energy efficiency increased, Power and Energy Losses reduced, Grid selectivity achieved, Three phase feeder load balanced.

Although the location of the MVROT in the Pilot Project was not ideal to fully demonstrate the efficiency and benefits of MVROT technology, these are still great results. MVROT was installed about 1.8 km from the substation and just over one kilometre of the power line is underground cable. MVROT performs best at further distances from the substation.

These live, dynamic, field data records and results are proof of the benefits of EGC's patented technology use in live distribution grids, and that this technology is superior for dealing with poor quality power, unbalanced systems, and overloaded distribution systems. MVROT technology is economically superior with fast implementation within the existing grids and its use is generating capital return as it significantly reduces energy losses, create grids that works in ideal conditions, prolonging the life span of existing equipment, and reduce / eliminate harmonics.

MVROT has two PTs and one CT built in, as integral parts, being fully CSA[4] certified, so any auxiliary equipment connections are possible. This added opportunity to Utilities for accurate measures of any data, control, automatization, introduce hardware compatibility with SCADA systems, so these grids can become part of overall SMART distribution networks. Being dry type technology, it is environmentally friendly and no cancerogenic materials are present.

The trial installation of the MVROT has demonstrated the device is the least expensive solution for improving distribution line efficiencies, power quality and reliability. By adopting this approach utilities will increase the return on investment, reduce capital expenditures and improve power quality and reliability to its customers.

Applying this patented "METHOD AND SYSTEM" [1] can achieve the same results in any medium voltage grids. MVROT design will soon be available for higher medium voltages (up to 25kV).

All these benefits above were addressed in published White Paper[3] at 2018 CIGRÉ Canada Conference in Calgary, and with this Pilot Project field results[6] they are validated in the live grid.

BIBLIOGRAPHY

[1] US10205318: **METHOD AND SYSTEM FOR REDUCING LOSSES DURING DISTRIBUTION**
Patent issued effective February 12, 2019.

[2] US10650954: **LOSSES REDUCTION FOR ELECTRICAL POWER DISTRIBUTION**
Medium Voltage Regulator and Optimizing Terminal (MVROT) Patent issued effective May 12, 2020.

[3] White Paper, CIGRÉ - W2.07 – Abs 12" published at Cigré conference 2018 in Calgary.
Innovative and Effective Method and System for Voltage Improvement, Power Quality and Reduction of Losses in Electrical Power Distribution
A. Lemez, - Energo-Group d.o.o., Sarajevo, Bosnia and Herzegovina
K. Lakiko, D. Lemez, - Energo Group Canada Inc., Calgary, AB - Canada

[4] MVROT CSA Certification: http://www.egcanada.ca/PDF/MVROT.pdf

[5] Canadian Electricity Association and Infrastructure, 2018 Sustainable Electricity Annual Report, https://electricity.ca/wp-content/uploads/2018/11/CEA_18-280_AR_E_WEB.pdf

[6] Pilot Project full report issued to Manitoba Hydro and published at EGC website.
https://www.egcanada.ca/PilotProject.html