Using TESLA Power System Monitoring in Distribution Systems

The TESLA multifunctional data recorder has been widely used by North American utilities (both in the USA and in Canada) for a wide range of applications in generation, transmission and distribution systems. One major Canadian utility has employed the TESLA Power System Recorder in distribution substations, resulting in a range of benefits. TESLA's unique features include flexible installation, power quality monitoring, trend recoding, DNP, continuous recoding of phasor data and fault location. Its advanced communication features such as IEC 61850, together with its recording capabilities, provide versatile and complete monitoring of power system health.

Flexible Installation

The TESLA recorder provides the following installation options:

- Configurable voltage or current inputs, up to 36 channels per TESLA unit
- Current inputs via split core CTs for system integration without power interruptions
- Flexible setting scaling for voltage, current and power enables the same TESLA to take measurements from different voltage levels
- Up to four TESLA units can be combined into cooperative operation mode enabling fault and events to be combined into a single file
- Data from multiple TESLA units located at different geographical locations can be collected into the central data collection program

This large Canadian utility employs TESLA at the following distribution levels ranging from 4 kV to 66 kV.

Sharing Data from Transmission and Distribution Level

TESLA modules are being used in almost all the utility's transmission substations. Some of these transmission level substations include distribution level interconnections with multiple voltage levels. Figure 1 shows an application of TESLA where data is shared from both transmission and distribution networks. TESLA's capability to allow multiple setting scales enables this utility to optimize the number of TESLA devices used in their system.

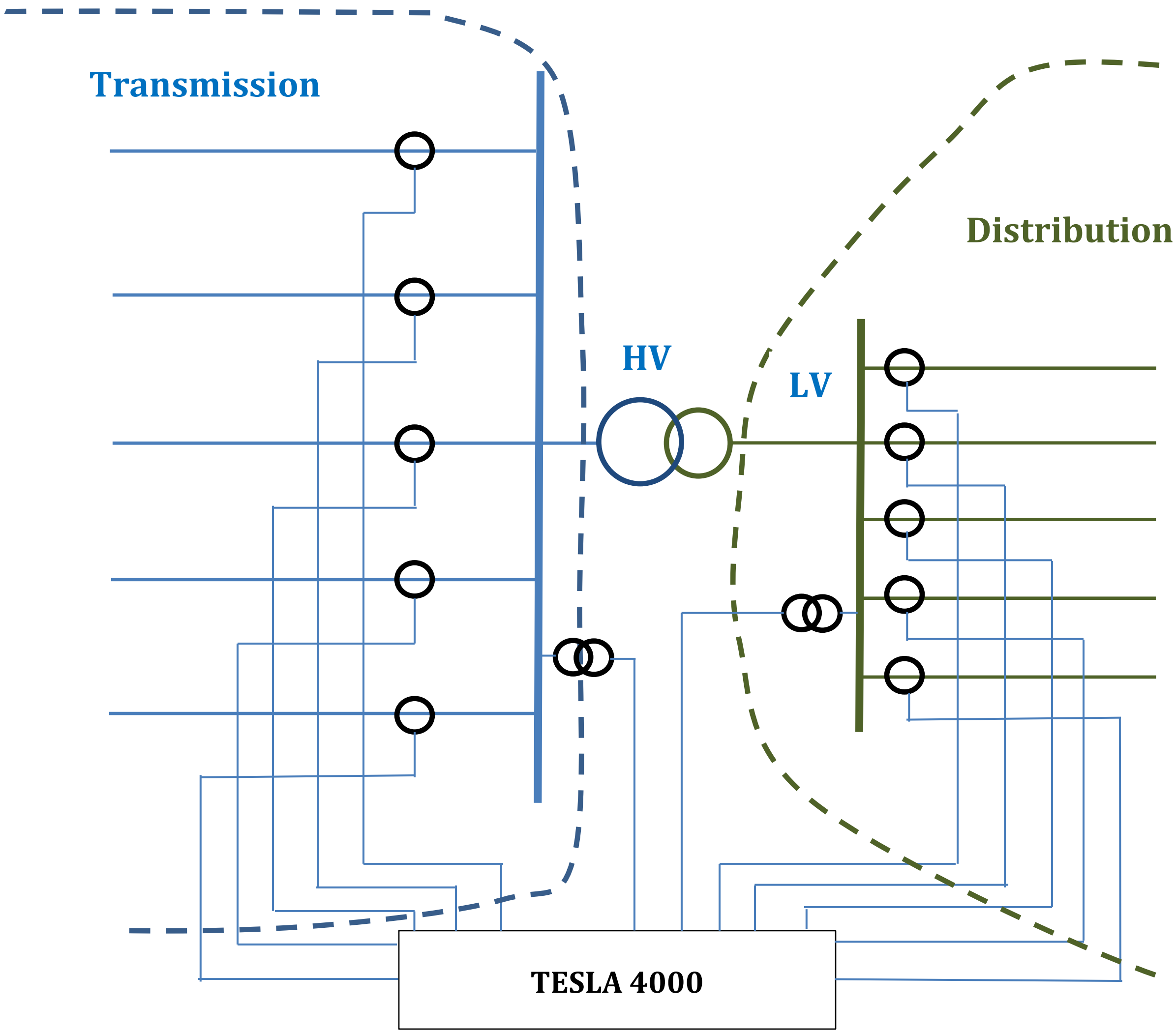


Figure 1: TESLA sharing data from both transmission and distribution sides

TESLA Using Measurements from Distribution Level

Use of TESLA to measure data from a single voltage level is straight forward. This utility uses TESLA in distribution level applications to take measurements from multiple feeders. Figure 2 shows an application example of a TESLA in a typical distribution substation.

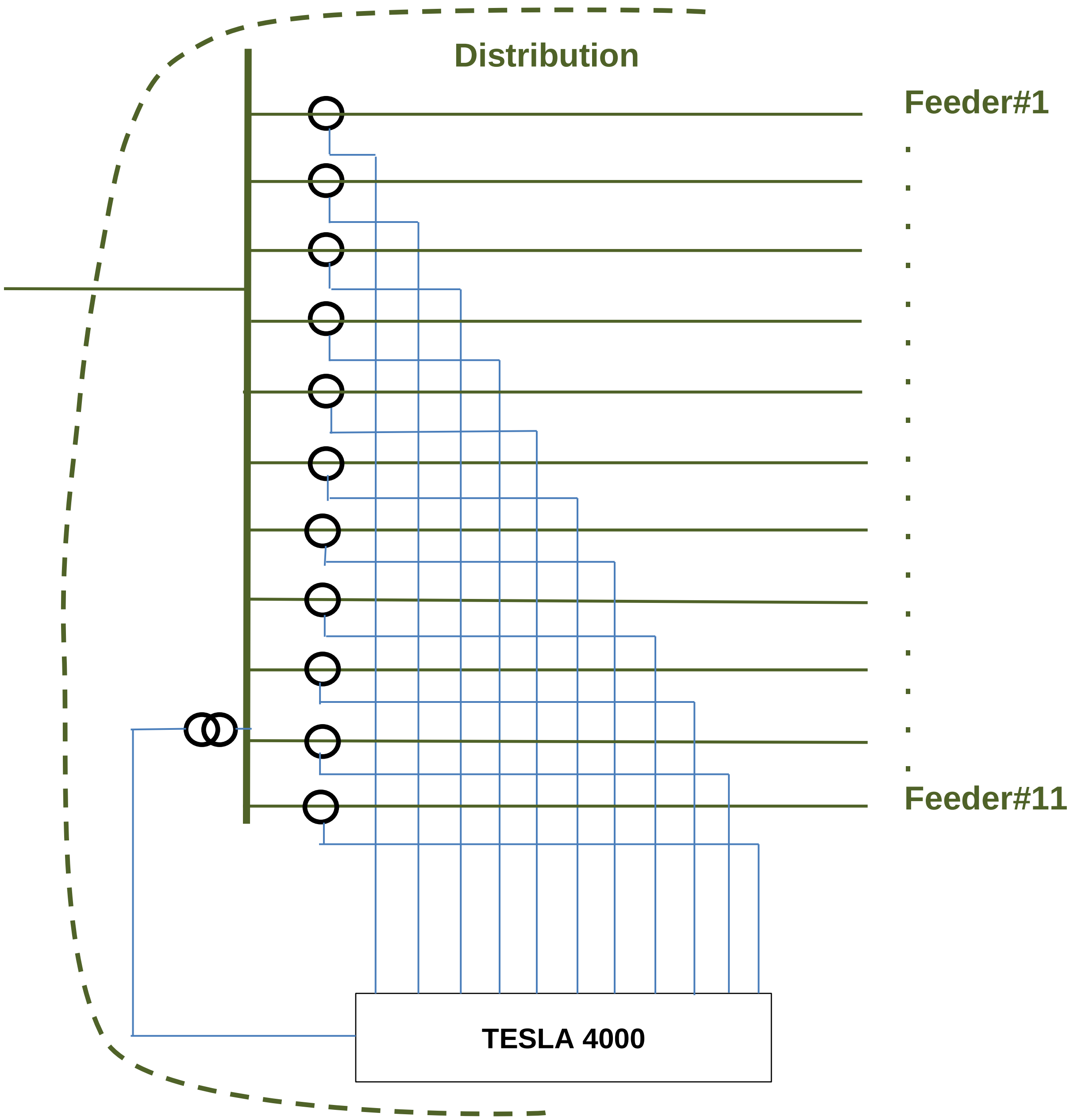
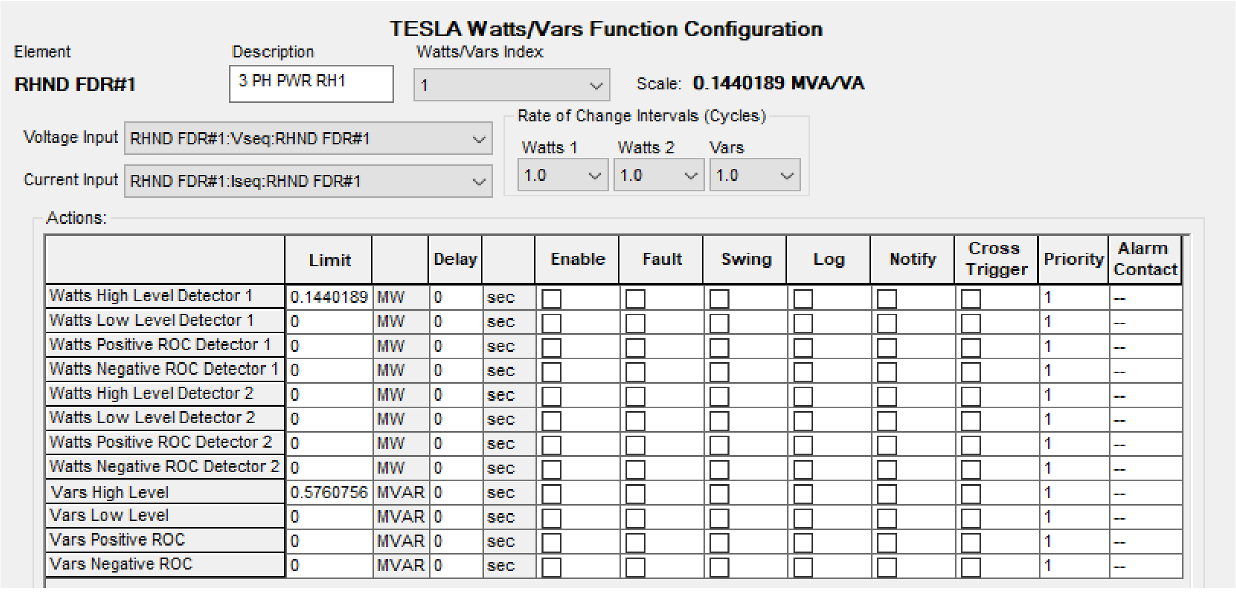


Figure 2: TESLA application in distribution feeders

Data Measurements

TESLA is available with two different analog channel options (18 channels or 36 channels). An 18-channel TESLA can be configured to monitor up to 5 feeders, and a 36-channel TESLA can be configured to monitor up to 11 feeders. TESLA's ability to calculate derived channels (summation, sequence, etc.) and sending that data via DNP gives unique benefits for some applications. The following measurements and features have been useful in this utility's application.

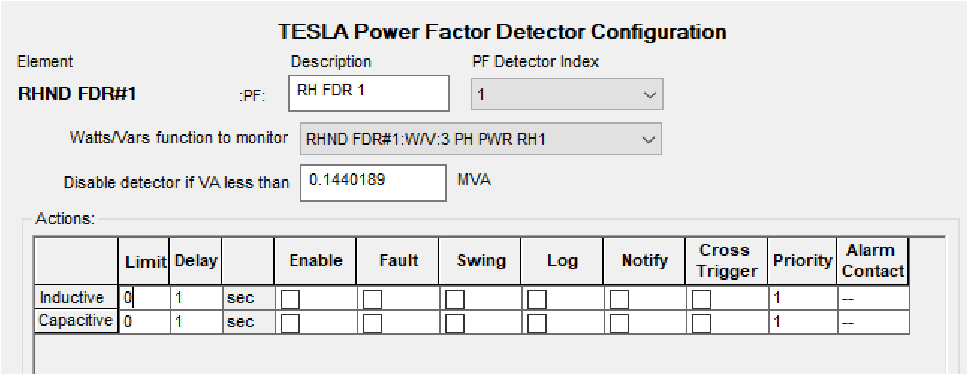
- **Active and reactive power:** TESLA is programmable to calculate active and reactive power, based on user-configurable voltage and current measurements.



	Limit		Delay		Enable	Fault	Swing	Log	Notify	Cross Trigger	Priority	Alarm Contact
Watts High Level Detector 1	0.1440189	MW	0	sec	☐	☐	☐	☐	☐	☐	1	--
Watts Low Level Detector 1	0	MW	0	sec	☐	☐	☐	☐	☐	☐	1	--
Watts Positive ROC Detector 1	0	MW	0	sec	☐	☐	☐	☐	☐	☐	1	--
Watts Negative ROC Detector 1	0	MW	0	sec	☐	☐	☐	☐	☐	☐	1	--
Watts High Level Detector 2	0	MW	0	sec	☐	☐	☐	☐	☐	☐	1	--
Watts Low Level Detector 2	0	MW	0	sec	☐	☐	☐	☐	☐	☐	1	--
Watts Positive ROC Detector 2	0	MW	0	sec	☐	☐	☐	☐	☐	☐	1	--
Watts Negative ROC Detector 2	0	MW	0	sec	☐	☐	☐	☐	☐	☐	1	--
Vars High Level	0.5760756	MVAR	0	sec	☐	☐	☐	☐	☐	☐	1	--
Vars Low Level	0	MVAR	0	sec	☐	☐	☐	☐	☐	☐	1	--
Vars Positive ROC	0	MVAR	0	sec	☐	☐	☐	☐	☐	☐	1	--
Vars Negative ROC	0	MVAR	0	sec	☐	☐	☐	☐	☐	☐	1	--

Figure 3: TESLA settings for active power and reactive power measurements

- **Power factor:** Power factor for each distribution feeder or line can be configured based on active power and reactive power definitions.



	Limit	Delay		Enable	Fault	Swing	Log	Notify	Cross Trigger	Priority	Alarm Contact
Inductive	0	1	sec	☐	☐	☐	☐	☐	☐	1	--
Capacitive	0	1	sec	☐	☐	☐	☐	☐	☐	1	--

Figure 4: TESLA settings for power factor measurements

- **THD or harmonics:** TESLA can also be configured to monitor Total Harmonic Distortion (THD) or individual harmonics for each analog channel.

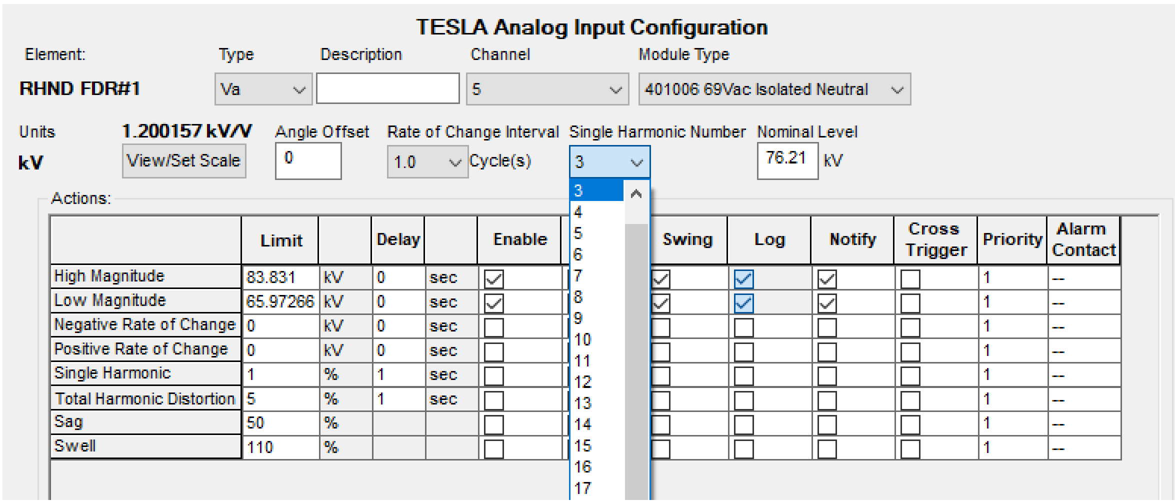


Figure 5: TESLA settings for harmonics and THD

- **Fault location:** Impedance-based fault location estimation functions available in TESLA can be used to identify and monitor faults in distribution lines. The utilities use fault location data to dispatch the maintenance crews during failures.

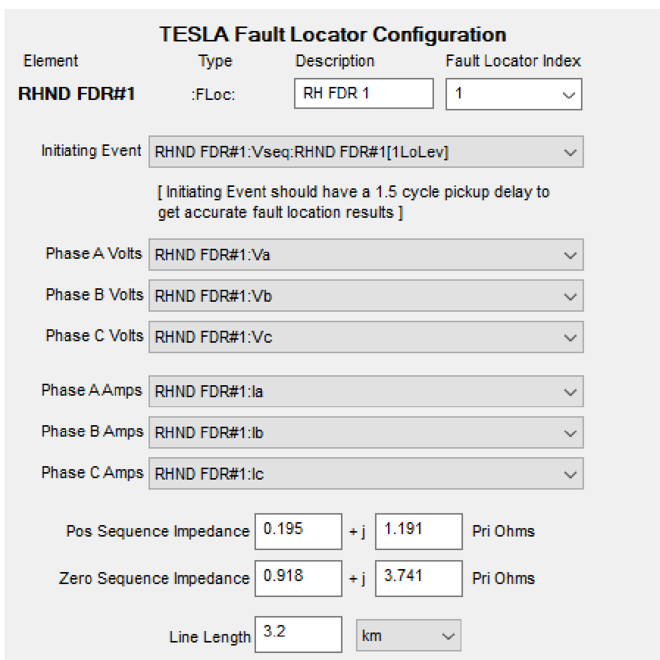


Figure 6: TESLA settings for fault locator calculators

- **Breaker status:** TESLA can be programmed to monitor breaker status via digital inputs.

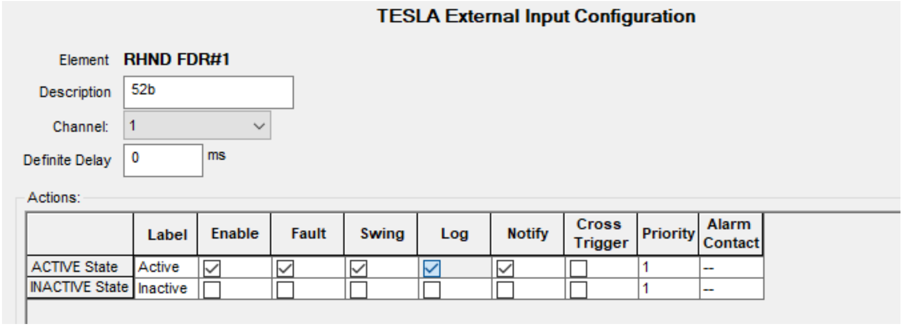
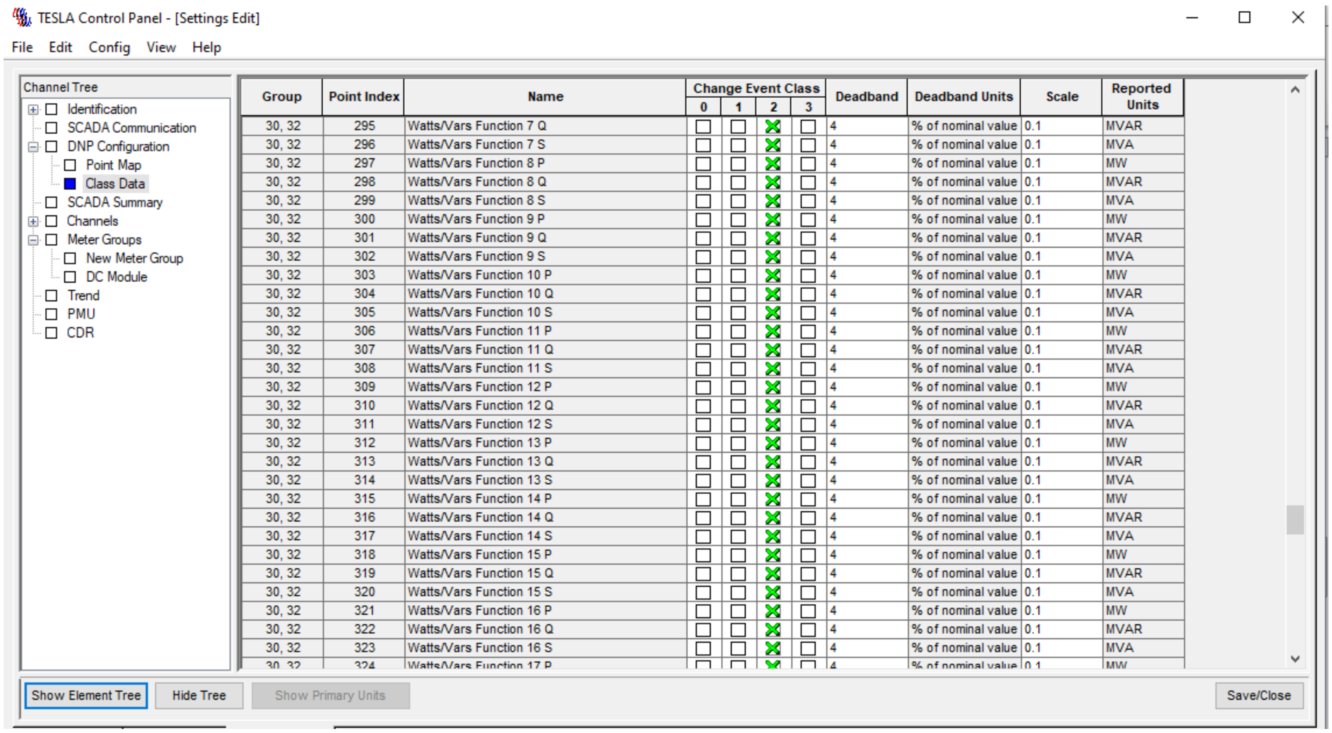


Figure 7: TESLA settings for breaker status monitoring

SCADA - Data Collection

As described in the previous section, this utility's collects distribution system measurements from TESLA units into a SCADA master station using DNP protocol. The system is programmed to send data at a rate of 10 samples per second. Data is archived and analyzed from time to time for decision making purposes.



Group	Point Index	Name	Change Event Class 0	1	2	3	Deadband	Deadband Units	Scale	Reported Units
30, 32	295	Watts/Vars Function 7 Q			X		4	% of nominal value	0.1	MVAR
30, 32	296	Watts/Vars Function 7 S			X		4	% of nominal value	0.1	MVA
30, 32	297	Watts/Vars Function 8 P			X		4	% of nominal value	0.1	MW
30, 32	298	Watts/Vars Function 8 Q			X		4	% of nominal value	0.1	MVAR
30, 32	299	Watts/Vars Function 8 S			X		4	% of nominal value	0.1	MVA
30, 32	300	Watts/Vars Function 9 P			X		4	% of nominal value	0.1	MW
30, 32	301	Watts/Vars Function 9 Q			X		4	% of nominal value	0.1	MVAR
30, 32	302	Watts/Vars Function 9 S			X		4	% of nominal value	0.1	MVA
30, 32	303	Watts/Vars Function 10 P			X		4	% of nominal value	0.1	MW
30, 32	304	Watts/Vars Function 10 Q			X		4	% of nominal value	0.1	MVAR
30, 32	305	Watts/Vars Function 10 S			X		4	% of nominal value	0.1	MVA
30, 32	306	Watts/Vars Function 11 P			X		4	% of nominal value	0.1	MW
30, 32	307	Watts/Vars Function 11 Q			X		4	% of nominal value	0.1	MVAR
30, 32	308	Watts/Vars Function 11 S			X		4	% of nominal value	0.1	MVA
30, 32	309	Watts/Vars Function 12 P			X		4	% of nominal value	0.1	MW
30, 32	310	Watts/Vars Function 12 Q			X		4	% of nominal value	0.1	MVAR
30, 32	311	Watts/Vars Function 12 S			X		4	% of nominal value	0.1	MVA
30, 32	312	Watts/Vars Function 13 P			X		4	% of nominal value	0.1	MW
30, 32	313	Watts/Vars Function 13 Q			X		4	% of nominal value	0.1	MVAR
30, 32	314	Watts/Vars Function 13 S			X		4	% of nominal value	0.1	MVA
30, 32	315	Watts/Vars Function 14 P			X		4	% of nominal value	0.1	MW
30, 32	316	Watts/Vars Function 14 Q			X		4	% of nominal value	0.1	MVAR
30, 32	317	Watts/Vars Function 14 S			X		4	% of nominal value	0.1	MVA
30, 32	318	Watts/Vars Function 15 P			X		4	% of nominal value	0.1	MW
30, 32	319	Watts/Vars Function 15 Q			X		4	% of nominal value	0.1	MVAR
30, 32	320	Watts/Vars Function 15 S			X		4	% of nominal value	0.1	MVA
30, 32	321	Watts/Vars Function 16 P			X		4	% of nominal value	0.1	MW
30, 32	322	Watts/Vars Function 16 Q			X		4	% of nominal value	0.1	MVAR
30, 32	323	Watts/Vars Function 16 S			X		4	% of nominal value	0.1	MVA
30, 32	324	Watts/Vars Function 17 P			X		4	% of nominal value	0.1	MW

Figure 8: TESLA DNP point map

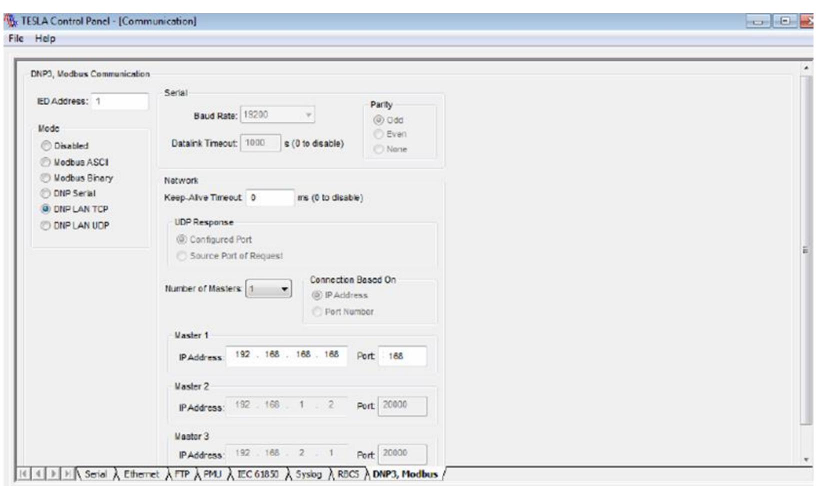


Figure 9: TESLA DNP communication settings

The utility has developed a central program to calculate average values using 10 seconds of data, based on a 1-hour moving window. The data captured by the central program are shown in Figures 10 and 11. Figure 10 shows the variations of phase current and imbalance current measurements obtained from four different feeders.

Name ▲	Value	Units	Trend	Maximum
N180|IA 1hr average	162.4	A		320.8
N180|IB 1hr average	204.53	A		394.34
N180|IC 1hr average	190.63	A		383.83
N180|Imbalance 1 hr average	9.5298	%		20.365
N180|OverCurrent Threshold	No Data			No Data

Name ▲	Value	Units	Trend	Maximum
N181|IA 1hr average	0.66937	A		1.0336
N181|IB 1hr average	1.1823	A		1.8618
N181|IC 1hr average	4.5114	A		7.5859
N181|Imbalance 1 hr average	113.74	%		153.54
N181|OverCurrent Threshold	No Data			No Data

Name ▲	Value	Units	Trend	Maximum
N184|IA 1hr average	238.57	A		410.28
N184|IB 1hr average	191.53	A		310.48
N184|IC 1hr average	225.96	A		413.94
N184|Imbalance 1 hr average	9.2109	%		14.664
N184|OverCurrent Threshold	No Data			No Data

Name ▲	Value	Units	Trend	Maximum
N186|IA 1hr average	144.44	A		186.55
N186|IB 1hr average	150.39	A		195.26
N186|IC 1hr average	131.35	A		153.46
N186|Imbalance 1 hr average	5.8359	%		13.923
N186|OverCurrent Threshold	No Data			No Data

Figure 10: Variation of feeder currents

Figure 11 shows the variations of active power, reactive power and apparent power, measured on two feeders.

Name	Value	Units	Trend	Maximum
BK1|MVA 1 hr average	1.3686	MVA		2.6084
BK1|MVAR 1 hr average	0.35815	MVAR		0.605
BK1|MW 1 hr average	1.3268	MW		2.5306

Name	Value	Units	Trend	Maximum
BK2|MVA 1 hr average	3.4443	MVA		5.1447
BK2|MVAR 1 hr average	1.0292	MVAR		1.5604
BK2|MW 1 hr average	3.2789	MW		4.9068

Figure 11: Variations of feeder power (active and reactive)

Data Analysis

Analysis of data is the most important step in the data collection process. Centrally collected measurements are archived and analyzed for following purposes.

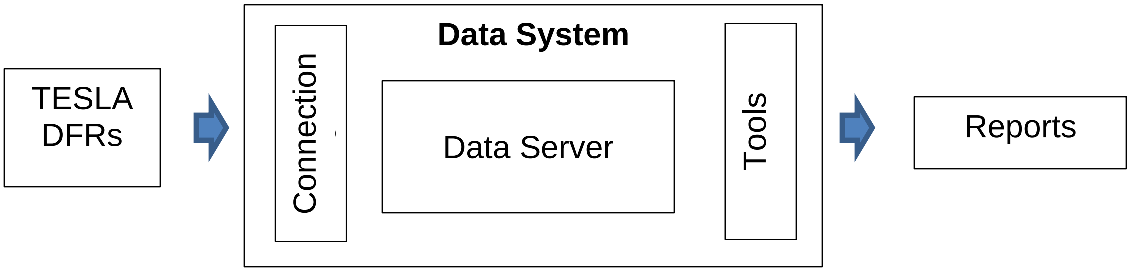


Figure 12: Overview of utility's data system

Identification of expansion requirements for the distribution system

Expansion of the distribution network involves adding extra substations, transformers and distribution lines in the system. This utility can monitor and analyze data to compare ongoing electricity demand against overall capabilities of the distribution system; they can predict and define short-term and long-term expansion requirements based on actual customer demand.

Optimization or redirection of power flows

Optimization or redirection of power flows is one of the important considerations in distribution utility applications. Expansion can be optimized or delayed if the existing distribution system (transformers and lines) is capable of handling ongoing demand. Detailed analysis enables this utility to effectively use its resources based on an understanding of generation and transmission investment options.

Analysis of events, failures and faults on the distribution network

By collecting data from the distribution feeder, this utility can analyze the events, faults and failures associated with the distribution lines, distribution transformers and other distribution equipment. Aging effects and system losses can also be identified and analyzed.

Monitoring of power flows at DER interconnections

Bi-directional power flows are quite common in applications with distributed energy resources. TESLA is capable of monitoring directional power flows and its additional recoding and monitoring features make it suitable for DER applications.

Future Considerations

Data collected and stored at central locations can be fed into an intelligent data analysis tool for automated analysis. This utility is looking to integrate these tools into their system to automate the current manual-analysis process.

This utility is currently collecting DNP data, but TESLA is also capable of sending recording data in continuous form. This data can be collected by the central data collection program (RecordBase Central Station (RBCS) tool). The RBCS tool is also capable of collecting other types of data such as fault data and swing data. This utility is considering synchrophasor applications for distribution systems. TESLA is capable of sending up to 36 phasor measurements, power measurements, additional frequency measurements, and digital signals. Even if the TESLA is not used to stream synchrophasors into a PDC for synchrophasor applications, when configured as a PMU, the phasors collected by the TESLA CDR are indeed synchrophasors and can be stored for future analysis.

References

[1] TESLA 4000 User Manual, ERLPhase Power Technologies Ltd., 2019.

[2] Data to Wisdom: Big Data and Analytics in the Canadian Electricity Industry, Canadian Electricity Association, 2017.

[3] RecordBase Central Station User Manual, ERLPhase Power Technologies Ltd., 2020.