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Design and Implementation of Power Quality Relaying for Renewable (Inverter-Based) and Synchronous Generation at Dominion Virginia Power

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SUMMARY

This paper outlines Dominion Virginia Power's approach to power quality relaying design and implementation based on IEEE Std. 519-2014: *IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems*, IEEE Std. 1453-2015: *IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems*, and IEEE Std. 1159-2009: *IEEE Recommended practice for Monitoring Electric Power Quality*. The Dominion Virginia Power service territory has numerous generation interconnection requests for various types of renewable generation with a majority being solar.

KEYWORDS

Power Quality, Relaying, Inverter-Based Generation

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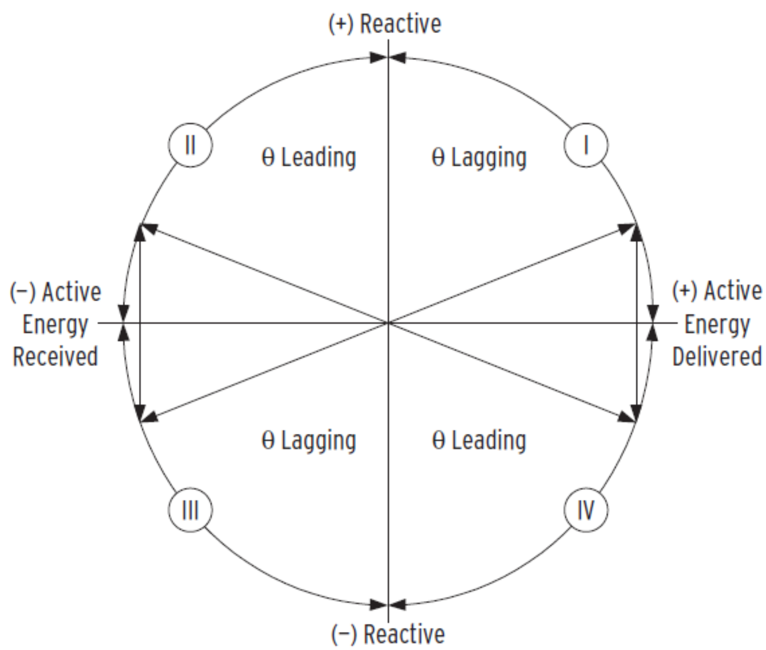
1. INTRODUCTION

The motivation for this work stems from the magnitude of interconnection requests within both the PJM interconnection queue, and the Virginia and North Carolina state jurisdictional queues. Historically, traditional synchronous generation interconnection requests have had a much lower fruition rate than renewable or distributed generation resources through each of the feasibility, system impact, and facilities study phases. PJM received 42 solar generation interconnection requests from December 1st, 2015 to May 29th, 2016. These 42 solar facilities combine for over 1000 megawatts capacity, and 2000 megawatt hours of total energy. The paper will discuss aspects of relay logic design, communications and data architecture, and where we are today with one transmission level solar interconnect at Dominion Virginia Power.

2. DESIGN AND DEVELOPMENT OF THE DVP POWER QUALITY RELAY

Dominion Virginia Power's power quality relay design includes elements monitoring over-frequency, under-frequency, over-voltage, under-voltage, power factor, imbalance, harmonics (THD and TDD), and flicker. Dominion Virginia Power is utilizing the SEL-735 to perform these functions. The SEL-735 has built in "Four-Quadrant VAR Metering" that we can use to take action, when necessary, for over-frequency, under-frequency, over-voltage, and under-voltage conditions.



Quadrant	Power Factor	Watts	Vars
I	Lag	Delivered (+)	Delivered (+)
II	Lead	Received (-)	Delivered (+)
III	Lag	Received (-)	Received (-)
IV	Lead	Delivered (+)	Received (-)

Figure 1: Four-Quadrant Control [1]

Utilizing four-quadrant control gives the protection scheme added security so action is not taken that would negatively impact the transmission system. For example, if the Dominion Virginia Power system were to experience a FIDVR (Fault Induced Delayed Voltage Recovery) event that diminished the voltage significantly below nominal, and a nearby solar generation facility were operating in quadrant I (delivering real and reactive power), tripping the generation offline would only exacerbate the condition of the transmission system.

Power Quality Function	Pseudo-Relay Logic
Under-voltage (UV)	UV and (QIII or QIV) = ACTION
Over-voltage (OV)	OV and (QII or QI) = ACTION
Under-frequency (UF)	UF and (QII or QIII) = ACTION
Over-frequency (OF)	OF and (QI or QIV) = ACTION

Table 1: Actionable Conditions for Under/Over-Voltage and Under/Over-Frequency

We can generalize by saying, "adverse condition and adverse operating points for said condition requires action." Action can be substituted for anything: tripping, changing the generator set-point, or triggering an event record. At this time, Dominion Virginia Power is opting to trigger an event record. In the future, tripping after some delay may be suitable if the generation is consistently the source of adverse operating conditions.

The expectation for all renewable generation facilities is to generate between 0.95 power factor leading or lagging.

The voltage and current imbalance is measured at the interconnect location. *IEEE Recommended Practice for Monitoring Electric Power Quality*, IEEE Std. 1159-2009, dictates voltage and current imbalance must be between 0.5%-2% and 1.0-30% respectively [2]. Dominion Virginia Power has experienced significant current imbalance on various voltage levels and is considering 2% voltage imbalance and 20% current imbalance as adverse operating points requiring examination.

Dominion Virginia Power has implemented the statistical based approach from the *IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems*, IEEE Std. 519-2014, in the SEL-735 [3]. The 10 minute THD values are readily available from the relay, and TDD values are implemented by taking the ratio of facility output divided by the facility contractual output multiplied by the THD. Each of the 10 minute THD or TDD values are compared with the applicable limits outlined in IEEE Std. 519-2014 Table 1 through Table 4 and a counter increments if the value of the 10 minute calculation period exceeds the limit. If the generation facility's weekly voltage THD and current TDD count exceeds 50 then the generation facility has violated the weekly 95th percentile short time (10 min) value in IEEE Std. 519-2014.

Similarly to the harmonic statistical approach, the flicker statistical based approach also considers 10 minute aggregates (called P_{st} for short-term) where criteria is outlined in Table 2 of *IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems*, IEEE Std. 1453-2015 [4].

While Dominion Virginia Power acknowledges the 99th percentile values for both harmonic content and for flicker, during the initial assessment period we will only look towards a more relaxed relaying criteria.

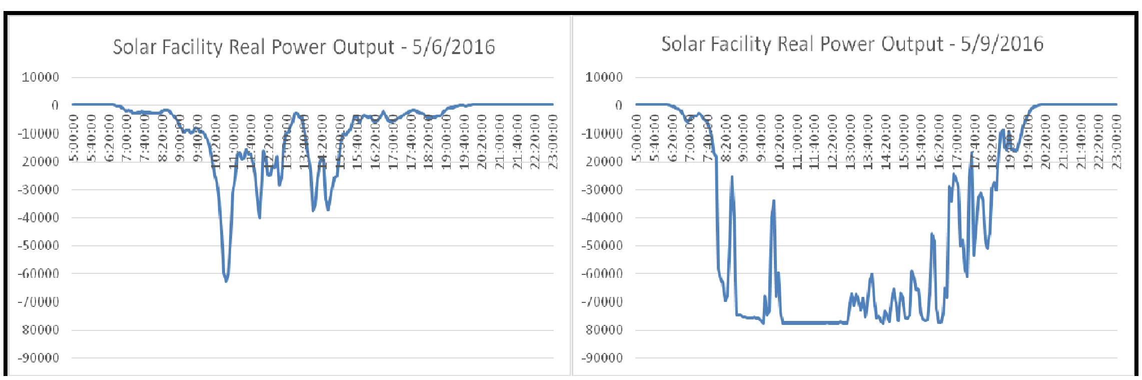
3. COMMUNICATION AND DATA CONSIDERATIONS

The purpose of the power quality relay in the first phase of development is to acquire data to help us better understand the behaviour of individual facilities and how these facilities interact with Dominion's electric transmission system during normal operation and abnormal events. Data is presently stored locally on the relay in what the SEL-735 calls load profiles. Each of the six load profiles is set up to store sets of average operational data (current, voltage, power, and frequency) in 5 minute intervals for 366 days, average total harmonic distortion data (current THD, and voltage THD) in 60 minute intervals for 366 days, average individual phase harmonic data (harmonics 1-5, 7, 9, and 11) in 60 minute intervals for 366 days, end-of-interval flicker data (PLT, and PST) in 10 minute intervals for 366 days, and maximum and minimum operational data in 5 minute intervals for the previous 5 days. The two primary limitations of this system are availability of storage space on the relay and accessibility of the data.

When the new power quality relaying design is put into service (Fall 2016), we will begin streaming power quality data back to our OSIsoft PI System database. We plan to put additional flags or triggers in place to notify a select few engineers when criteria is approaching or has breached a limit specified in section 2 of this paper. This data is also readily available to all Dominion Virginia Power engineers who may want to perform their own statistical analysis, visualize and trend data, set up personal calculations, or be notified if data exceeds a certain bound. Operational data (current, voltage, real power, reactive power, apparent power, frequency, and power factor), individual phase voltage THD and calculated current TDD, individual phase harmonic data (3 second aggregate, instantaneous magnitude, and instantaneous angle), voltage and current imbalance, and counter register information for statistical approach of IEEE-519-2014 and IEEE-1453-2015 implementation will be streamed to the PI System database via DNP protocol.

4. WHERE WE ARE TODAY: SOLAR FACILITY #1 HARMONIC CONTENT

Solar Facility #1 was the first facility interconnected to Dominion Virginia Power's 230 kV electric transmission system. Solar Facility #1 is an 80 MW solar photovoltaic facility connected in the eastern portion of Dominion Virginia Power. The figures below show real power output, percent current THD, and flicker from Solar Facility #1 on a cloudy day with intermittent output (5/6/2016) versus a relatively consistent day (5/9/2016).



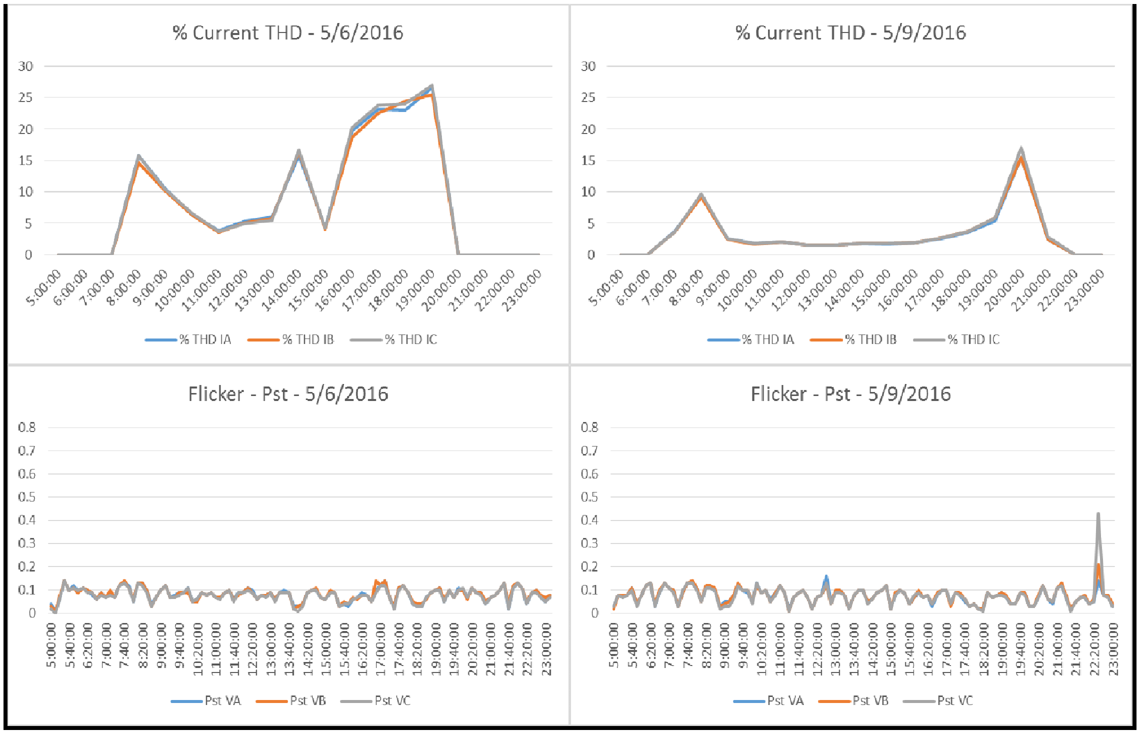


Figure 2: Solar Facility #1 Real Power, THD, and Flicker

From both graphs we can determine operation of the solar photovoltaic facility at very low output levels causes significant current THD, but current THD is misleading. We can take the same two graphs, apply the formula for TDD from section 2, and we see different results.

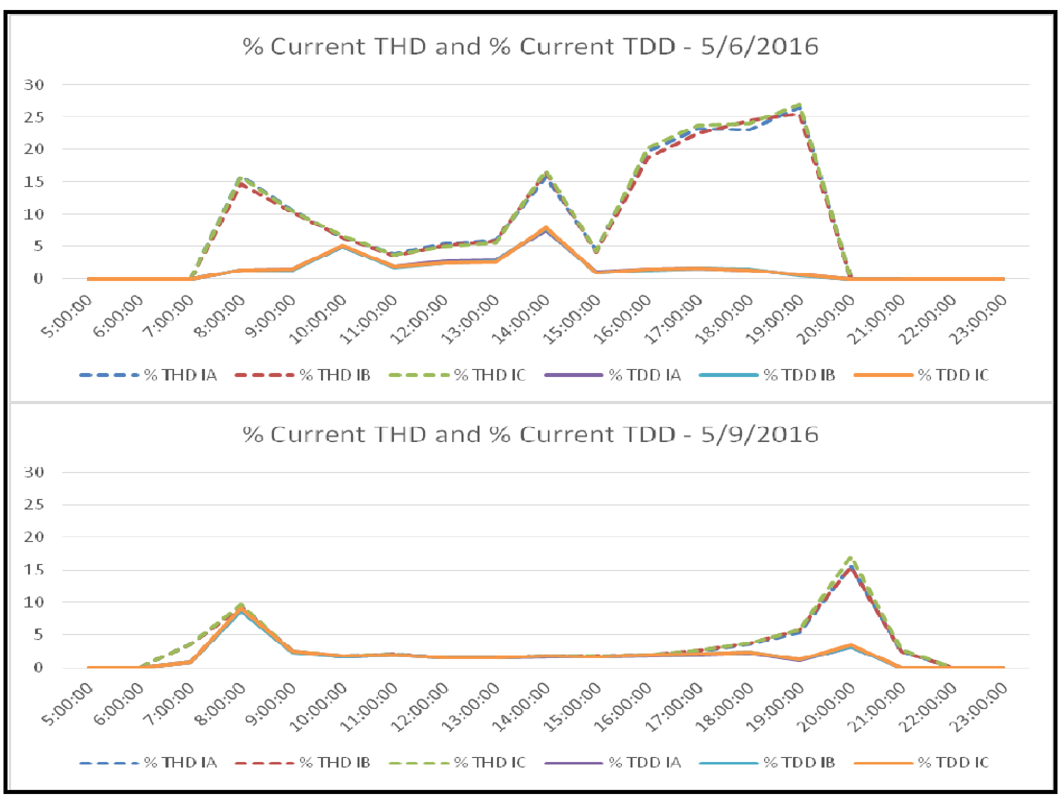


Figure 3: Solar Facility #1 TDD Calculation

On May 6th, 2016 we had TDD averages slightly over 5% during two periods, 10:00:00 and 14:00:00. On May 9th, 2016 we had TDD averages well over 5% around 8:00:00. IEEE-519-2014 calls for TDD limits on systems greater than 161 kV to be less than 1.5%; both days have steady-state averages exceeding this value.

While this data was gathered and plotted manually, our future goal is to utilize OSIsoft PI System to continue to make associations in steady-state generation performance and facility transient response to system disturbances. Our plan is to set up an automated power quality report on performance of inverter based generation, power electronic FACTs devices, and conventional synchronous generation as a baseline to predict and mitigate power quality issues in the future and associate power quality violations with performance and longevity of electric transmission assets.

BIBLIOGRAPHY

[1] Schweitzer Engineering Laboratories, *SEL-735,* 2015.

[2] *IEEE Recommended practice for Monitoring Electric Power Quality,* IEEE Std. 1159-2009.

[3] *IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems,* IEEE Std. 519-2014.

[4] *IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems,* IEEE Std. 1453-2015.