Using Open Source Modeling Tools To Enhance Engineering Analysis

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Abstract -- There are several very capable open source engineering analysis tools that a utility can use to assist in solving engineering analysis problems. Applying these open source applications, alongside a commercial engineering analysis application, can be a very cost effective way for utility engineers to solve problems presented by newer technologies, such as Solar and Wind DG and PEV charging, using the data they already have in their commercial applications.

In this paper we will use GridLAB-D, OpenDSS, and Milsoft's WindMil, to show examples of today's engineering analysis problems that can be solved using open source and commercial applications in concert with each other. The purpose of the paper is to show what is possible, and what is needed to use multiple analysis tools to solve more complex analysis. The purpose of the paper is not, for example, to complete a complex time series study on the affect of PV generation on a distribution network, which could be a paper on its own merit. The list below outlines some of the analysis projects that can be done with this approach and we will provide examples of at least two of them.

- Voltage Drop
- Basic PV Analysis
- Effects of voltage profiles for various times (peak wind/solar v. peak load v. off-peak)
- Harmonics
- Effects of EV charging

We will also outline the need for validated connectivity and asset information as the foundation analysis in any tool selected by the utility to accomplish their engineering analysis tasks.

Index Terms—**Advanced Metering Infrastructure (AMI), Data Analytics, Smart Grid, Smart Meters, SCADA (System Control and Data Acquisition), Distribution Analysis, Distribution Automation, Distribution State Estimation, Load Flow Analysis, Real Time Distribution Feeder Analysis, Active Grid Management, Big Data**

I. INTRODUCTION

Accurate, detailed modeling and analysis of the electric distribution network is essential to provide the most economical, safe, and reliable service to our communities. There is not a single analysis tool that is capable of doing all the analysis necessary to keep an electric distribution network operating at peak efficiency. In addition, both the analysis and models created by analysis systems have to be able to be consumed on both the engineering and operational teams at utilities. If there is not a common connectivity model, along with asset data that can be shared with the analysis applications, they cannot effectively work together. The cost of acquiring this foundational data for any utility, along with maintaining the data to keep an accurate connectivity and asset database, is expensive. It is essential that the connectivity and asset data be useable across the analysis applications.

The analysis applications used in this paper are WindMil from Milsoft Utility Solutions, Inc., GridLAB-D from PNNL, and OpenDSS[1] from EPRI. WindMil manages the electric distribution connectivity model, asset and equipment data. We will show how to export the connectivity and asset data into GridLAB-D and OpenDSS to perform other analysis that WindMil does not.

II. OVERVIEW OF THE CIRCUIT BEING ANALYZED

We chose not use the IEEE feeders for this paper. We will show a real utility electrical distribution network as an example for this paper. We will use Sub A, Feeders 1 and 2, located at Excelsior EMC and WindMil's connectivity model and data. We will export the data using WindMil's interface to GridLAB-D and OpenDSS and show that using the same database source, the results match doing basic analysis on the circuit. We will use GridLAB-D and OpenDSS to do further analysis on the circuits.

Prior to export, the WindMil circuit model database contains all data and equipment settings required to accurately run unbalanced impedance and unbalanced loading load flow.

Regulators are configured in the voltage drop analysis to use the step option. This option allows the regulators to be modeled and simulated with their actual number of taps and bandwidth, as well as regulator set-point and any active line drop compensation settings.

III. WINDMIL, GRIDLAB-D, AND OPENDSS RESULTS – BASE CASE

In this section, the results from running the base case, as entered into the WindMil distribution analysis software will be compared to the results from GridLAB-D and OpenDSS.

Table I shows the active power flow at the substation from each of the three distribution analysis software packages.

Substation Active Power (kW)			
	WindMil	GridLAB-D	OpenDSS
Phase A	841.0	841.1	840.4
Phase B	749.0	749.7	749.0
Phase C	681.0	680.3	680.2
Three-phase	2271.0	2271.2	2269.6

Table I. Substation Active Power for Base Case

Similarly, Table II shows the per-phase amperes from each of the three software packages, at the substation.

Substation Current (amperes)			
	WindMil	GridLAB-D	OpenDSS
Phase A	113.71	113.97	113.65
Phase B	100.78	100.77	100.74
Phase C	91.50	91.46	91.44

Table II. Substation Current for Base Case

Table III shows the per-phase voltages at the furthest three-phase bus from the substation.

Furthest Three-Phase Bus @ 9.7 miles (120V base)			
	WindMil	GridLAB-D	OpenDSS
Phase A	120.2	120.2	120.3
Phase B	118.9	118.6	119.0
Phase C	117.7	117.6	117.7

Table III. Substation Voltage for the Base Case

Fig. 1 shows a voltage profile plot for the two feeders supplied by Substation A. Both feeders are shown. The y-axis shows the magnitude of the bus and line voltages in per-unit voltage. The x-axis shows distance from the substation to each bus and line on both feeder 1 and feeder 2, in kilometers.
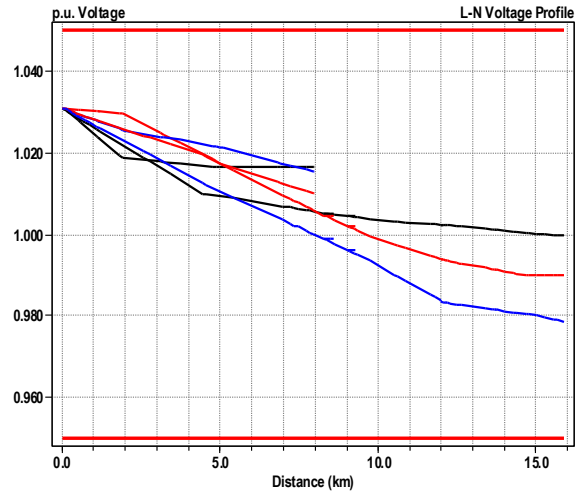

Fig. 1. Voltage Profile for Feeders Supplied by Substation A.

Reviewing the data in tables I, II, and III, the data export from WindMil, using the OpenDSS and GridLAB-D export function, shows the data originating from WindMil gives us very close to the same result in all three applications. We encourage utility engineers to go through this data validation step to insure that the data and model being exported can be used confidently in a study using GirdLab-D and OpenDSS.

IV. OPENDSS ANALYSIS

The base case model was exported by WindMil to OpenDSS and shown to be valid (in OpenDSS) in Section III. This section will show an analysis using the OpenDSS. The analysis will utilize one PV arrays rated at 750 kW. The inverter associated with the PV array is rated at 900 kW, or 1.2 times the Pmpp. The location of the PV is shown in Fig. 2.
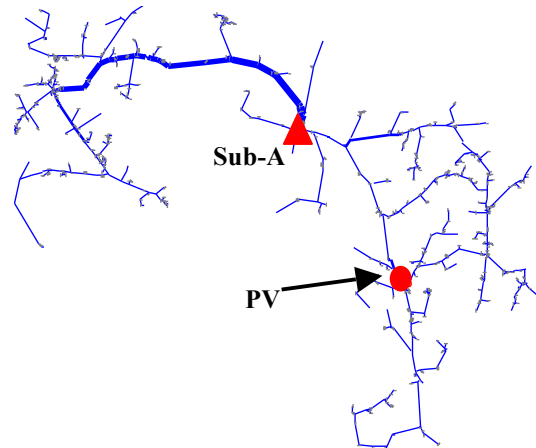

Fig. 2. Circuit model showing location of the 750 kW PV array.

The PV array is connected to the feeder via a 1000 kVA interconnect transformer. The higher-voltage winding is connected grounded-wye and the lower-voltage winding (where the PV is connected) is connected delta.

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This analysis is to determine the effects of changing from no output to full output from each PV on the terminal voltages and on the nearby primary voltage, as well as any possible movement of voltage regulators. The terminal voltage and the primary voltage, prior to any voltage regulator action increased from 1.02 per-unit voltage to 1.04 per-unit voltage.

Once the regulators were allowed to operate based on their control settings, two regulators near the PV array changed taps due to the change in voltage at the regulators due to the change in PV output. A regulator on B phase and a regulator on phase C moved two taps lower.

One approach to mitigating the effects of changes in PV output is to use a smart-inverter function called volt-var control[2,3]. Volt-var control uses a curve that defines the reactive power output as a function of terminal voltage. An example volt-var curve is shown in Fig. 3. Typically, the curve is defined in a manner that generates capacitive vars when the voltage is less than 1.0 per unit, to boost the voltage. The curve typically is defined to generate inductive vars when the voltage is greater than 1.0 per unit.
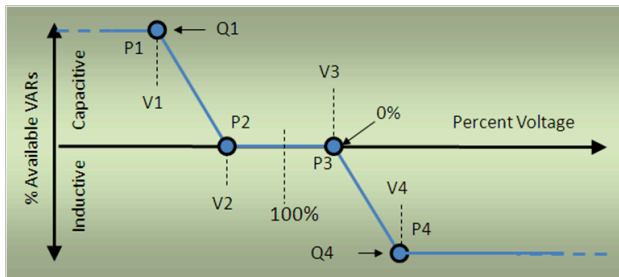

Fig. 3. Example volt-var curve.

By applying a smart inverter control that implements volt-var control mode, we are able to reduce the voltage change due to change in the PV active power output such that the regulators do not change taps.

The volt-var control mode with volt-var curve results in the generation of about 477 kvar, inductive. This is to counteract the voltage rise due to the active power output. This is approximately 96% of the maximum reactive power output that could be generated by the inverter with an active power output of 750 kW and an inverter size of 900 kVA.

V. GridLAB-D Analysis

The static load flow model was translated into the GridLAB-D modeling language and modified by adding time-series data. The time-series data can come from a number of resources, from prototypical load shapes to AMI measurements to public databases. In this model, the static spot loads are replaced with a combination of load shapes from a southern California utility and ELCAP load studies [4][5] from a hot summer day. The peak load value aligns

with the static load flow model (2.3 MW) and represents a primarily residential circuit. Static voltages at the swing node were replaced with 15-minute time-series voltages measured from a sub-transmission node. The substation load is shown in Fig. 4.
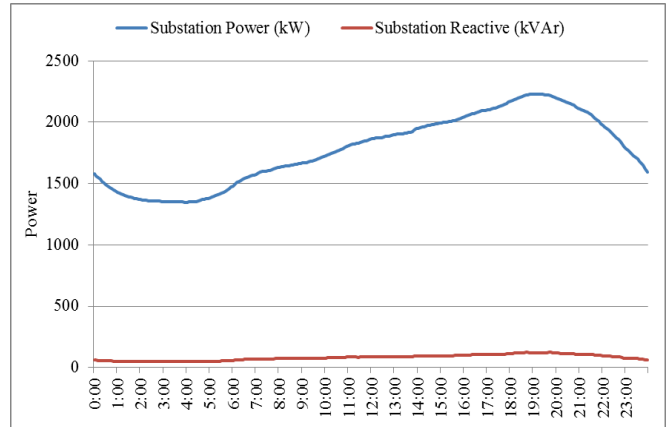

Fig. 4 Substation Load.

In addition, a solar array is added at node o1225_n. It is attached to the feeder via a three-phase WYE-WYE step-down transformer (12.47 kV to 240 V) and includes a series of inverter and solar panel models, which use solar irradiance data to calculate power output [6]. An 800 kVA, 1000 kVA, and 1200 kVA solar arrays are modeled. Modified solar irradiance data for a partly cloudy day from NREL's Measurement and Instrumentation Data Center is used to determine the output of the solar plant [7]. Power factor is set at unity. Fig. 5 shows the total solar power output of the 800 kVA case.
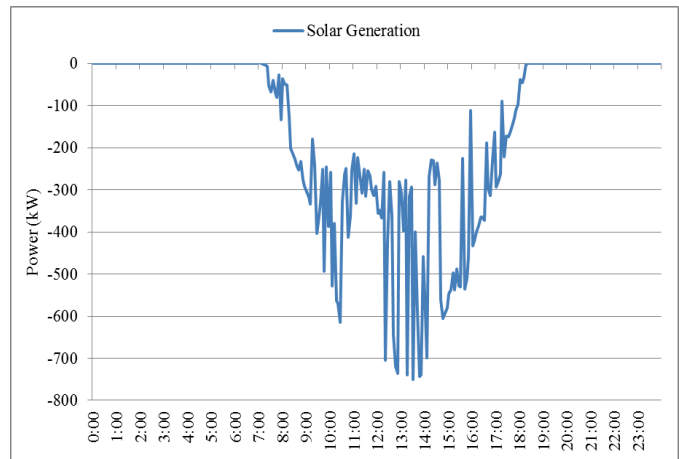

Fig. 5. Total Solar Power Output.

Transferring models between tools allows us to look at different aspects of the problem. For example, Table 1 shows a comparison of the daily real and reactive energy losses as a function of the size of the solar plant and compares this to the peak load flow loss study. The time-series model is better able to capture the low- and medium-load effects, predicting

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a 4.5% reduction in losses when the 800 kW solar plant is added. Some of the differences between the static model and time-series model can be corrected by performing multiple simulations at multiple load levels, however if data and models can be easily transferred between tools, then this becomes an unnecessary step and may provide better solutions.

	Real Losses (kWh)	Real Losses (%)	Reactive Losses (kVArh)
Static - No Solar	1,912	3.5%	2,459
Static - 800 kW Solar	1,702	4.7%	2,310
No Solar	1,196	2.8%	1,541
800 kW	1,141	2.9%	1,494
1000 kW	1,139	3.0%	1,494
1200 kW	1,145	3.1%	1,503

Table IV. Real/Reactive Losses

Another interesting side effect that can be observed is the impact on the regulator nearest the solar array. The number of tap changes observed increases by a significant amount (as high as 4 times) between the no solar and 1200 kW case.

This could have a significant impact on cost of operation and maintenance. With these types of models and the addition of time-series data, reliable information can be obtained about the effects and costs associated with the installation of the array prior to installation.

	RG086010 Daily Tap Count	
	Tap B	Tap C
No Solar	9	5
800 kW	15	15
1000 kW	19	19
1200 kW	37	21

Table V. Daily Tap Count

VI. SUMMARY

The acquisition and maintenance of data is expensive. Creating the ability for utilities to use the same data across multiple software applications that enhances their engineering capabilities is both foundational and powerful. It not only maximizes the utilities investment in data that they have collected in dollars, but the investment is further enhanced by enabling engineers to accomplish analysis on technologies such as solar and electric vehicles without having to recreate or find the data to complete the analysis. Utilities can use the best in class tools to solve problems.

We took three different applications, with the same model and data from WindMil, and came up with the same analysis results. All three applications have their strengths and weaknesses when it comes to analysis, and all three applications cannot operate without data. We look forward to sharing more detailed analysis using this concept of data and models interoperating between applications.

AUTHOR INFORMATION

Stanley E. McHann, Jr. is Chief Technology Officer at Milsoft Utility Solutions, Inc. He has served in engineering, and senior technical staff positions at Dell Computers, Tandem Computers, 3Com, Cadence Design Systems, and Landis + Gyr prior to joining Milsoft.

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Wes Sunderman (M'1991) is a Sr. Project Engineer for the Electric Power Research Institute (EPRI) in Knoxville, TN. His research interests include solar integration into distribution systems, neutral-earth voltages including mitigation measures, and distribution system analysis. He received his Bachelor's degree from, John Brown University (1991). From 1997 to 2000 he served as Power Quality Engineer at Square D Company in LaVergne, TN. From 1991 to 1997 he held various positions at Southwestern Electric Power Company in Shreveport, LA, culminating in the position of power quality engineer for the company's largest industrial customers.

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