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Energy Storage Modeling for Distribution Planning

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Abstract— **Storage is being proposed to solve many issues on the electric power grid, especially those issues related to renewable generation such as wind and solar generation. Some North American state and provincial regulators are requiring large amounts of storage to be installed to support anticipated needs of the power grid. Much of that new storage is expected to be connected to distribution feeders.**

Distribution planners lack tools and methods to assess storage impact on distribution system capacity, reliability, and power quality. Planners are accustomed to static power flow calculations, but accurate analysis of storage requires sequential-time simulation. This paper describes modeling storage for various types of simulations on distribution systems for different time frames typically involved. The basic impact on capacity and voltage regulation can generally be evaluated in simulations with 15-minute to 1-hour intervals. Evaluations of smoothing of renewable generation variations may require simulations with time step sizes of 1 minute or less. Evaluations of such things as frequency control of microgrids and performance during transient disturbances will require dynamics analysis in intervals ranging from seconds down to microseconds. This paper is a summary of recent EPRI research in modeling energy storage for planning studies.

Index Terms—**Distribution System Analysis, Power Distribution Planning, Dispersed Storage and Generation, Solar Power Generation, Wind Power Generation**

I. Introduction

Energy storage devices are being proposed as the solution to various operational and reliability problems on power systems mainly due to large amounts of variable and uncertain power sources such as wind and solar generation. Some locations such as the US state of California and the Canadian province of Ontario have been particularly aggressive in adding large amounts of storage to the grid (100's of MW of capacity) to counter the anticipated problems from these sources of generation.. A certain amount of this storage will undoubtedly be installed on distribution systems.

Recent storms in the US such as the occurrence of the historic derecho (straight-line winds) and Storm Sandy in June and October of 2012, respectively, drew considerable attention to the topic of resiliency of the grid. Many customers were without electric power for several days and some for several weeks. This prompted calls for microgrids to be built so that parts of the distribution system can be operated in islands until power lines damaged by the storms can be repaired to re-establish grid connection. Energy storage is a key part of making such efforts successful.

Although a great deal of the storage will likely be installed on the distribution system, much of it will be controlled by the area grid operator for the benefit of the transmission grid. The distribution system is simply a host for the storage. If the grid frequency begins to droop due to loss of wind generation, the distributed storage will be called upon to provide power to counter the downward ramping of the wind turbines. If the frequency increases above nominal, the storage elements would switch to charging mode and absorb power up to maximum storage capacity to slow the frequency. This gives time for more conventional generation sources to re-dispatch to meet the load.

Storage is *energy* storage, measured in kWh or MWh, while most distribution planning studies are focused on the capacity to deliver *power*, measured in kW or MW. Energy is the time integral of power, so modeling storage naturally adds the time dimension to the planning problem, which is both useful and challenging at the same time. One ramification is that static power flow solutions will no longer provide adequate insight into many of the planning problems that planners will face. Planners must simulate the system over a reasonable amount of time to get the correct answer when there are time-variant resources such as solar PV and wind generation.

II. Applications of Storage on Distribution Systems

Some of the applications proposed for storage installed at the Distribution primary (MV) or secondary (LV) level include:

- Compensating for, or smoothing, solar PV power output ramping.
- Extending the power output from solar PV to meet the early evening peak demand. On many distribution systems the peak load occurs after the sun has gone down.
- Support of Transmission grid: Compensating for the loss of solar power at the end of the day to reduce the need to for fast ramping of conventional sources;

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stabilizing the grid during periods of high variability of renewable resources.

- Extend the capacity of an existing distribution substation or feeder.
- Supporting alternate feeds for temporary reconfiguration.
- Controlling the frequency of a microgrid.
- Increase the available short-circuit current of a microgrid so that it is more capable of operating distribution system and customer protective devices.
- Reducing the cost of electricity to a given power purchaser by charging off-peak when the energy is cheaper and discharging to supply load during peak demand periods.

There are undoubtedly many more potential applications for storage, but this list gives an idea of why there is much interest in storage on utility power distribution systems.

III. Distribution Planning Issues Introduced By Energy Storage

Installing energy storage devices on the power distribution system introduces several issues to be considered by planners. These issues include:

- Overvoltages while discharging. The impact depends on the location and capacity of the storage devices and is similar to the impact which is evaluated for hosting capacity analysis of inverter-based solar PV systems. This could be a particular problem when storage is dispatched for purposes other than the benefit of the local feeder. The storage dispatch could occur at night or any other light loading time.
- Low voltages while charging. To reach the goals of several 100 MW of storage across a utility service area, one can easily imagine that the capacity of storage devices on a given distribution feeder could be several hundred kW to a few MW.
- Voltage regulation while compensating for transmission grid support. The power produced or consumed may very well have no relevance to the behavior of the load on the distribution system.
- Interference with overcurrent protection practices. All distributed power sources have the potential to disrupt long-standing utility practices during fault clearing operations. Since most storage devices currently being considered have inverter-based interfaces to the utility grid, short-circuit current contributions are expected to be 110-120% of rated current. With several large devices this is sufficient to disrupt fast-tripping/fuse-saving coordination. On the other hand, it is insufficient to operate conventional overcurrent devices such as fuses, reclosers, and circuit breakers (see next bullet).
- Sufficient short circuit capacity to operate overcurrent protective devices when operating as a microgrid. This is a common problem with all smaller resources and calls for a different approach to distribution system protection based more on voltage quantities and impedance relaying. Even if the protection on the utility-owned distribution system is modified to accommodate low-capacity sources, the vast majority of consumers will still have conventional overcurrent breakers that require a strong short-circuit current to operate.

IV. Sequential Time Simulation

Distribution system load shapes have historically been quite regular with a daily or weekly cycle. Many assumptions that planners make on the ratings of equipment are based on the expectation these load shapes will continue. By the time the OpenDSS program was designed in 1997, EPRI researchers had recognized that it is not possible to get the correct answer for distribution planning problems involving DER unless a series of power flow solutions are performed over a significant time period. Sequential-time power flow capability is now accepted practice in advanced distribution planning methods for analyzing any resource or new load that significantly alters the typical load shape on the distribution system.

It will be necessary to continue to exploit this capability to accurately account for storage in distribution planning. Storage is not only a variable resource, but it is a limited resource and simulation tools must keep an accurate accounting of the amount of energy stored and available to supply power to meet demand. Some storage technologies also have a limit on the ramp rate of the main storage element.

Storage not only must provide power when called upon but must be recharged from some resource – usually the same grid – at a later time. The charge-discharge cycle is lossy, which may play a significant role in the economics and, thus, dictate the application. There are also idling losses during periods when a storage device is neither discharging nor charging. These losses include such things as keeping batteries cool or warm depending on the ambient temperature and can be significant. Thus, the planning problem now is more than simply determining the power-delivery capacity to meet the forecasted peak demand from a bulk power source that can be assumed to be always available.

V. Simulation Modes

EPRI has been studying the distribution planning problem with storage since the beginning of the Smart Grid Demo initiative. One of the first demo projects was the AEP Community Energy Storage (CES) demo (2009-2012), Six basic simulation *modes* were identified for modeling storage for distribution system analysis based on the application:

1. **Static Mode:** This is the conventional solution of one power flow state with the storage device model manually set to *discharging* or *charging* at specified rates, or *idling*. This provides a partial planning picture by simulating limiting conditions but does not reveal issues that are exposed through time-series simulation.
2. **Time Mode:** Trigger the storage element at a specified time of day to discharge or charge at a specified constant level.
3. **Peak Shave Mode:** Triggers the storage element to discharge when the load measured at a selected control location such as the substation exceeds a specified peak value and attempts to produce sufficient power to limit

the net load power to the specified value. Charging is performed separately at a scheduled time.

4. **Load Following Mode:** Similar to peak shave mode except that the storage element is triggered to discharge at a specified time predicted through a short-term load forecast when it will be necessary to offset load demand. Then the storage controller attempts to produce sufficient power to limit the net load to the value at the time of triggering.
5. **Loadshape Following Mode:** The storage charge and discharge cycle is determined by a predefined shape. This capability gives the planner the flexibility to investigate many different scenarios without requiring hard-coded computer algorithms to be implemented in the planning tools.
6. **Dynamics Mode:** This is an advanced mode of analysis for modeling fast-changing phenomena such as frequency control on microgrids or fault current contributions.

EPRI has implemented examples of these simulation modes in the open-source OpenDSS software available on the internet. The code is available for interested researchers and software developers to inspect.

Modes 2 through 5 are designed for sequential-time power flow simulations with time steps of typically 15 min to 1 h for common power and energy capacity evaluations. To study using storage to compensate for rapidly-varying power sources such as solar PV generation, a time step as small as 1 s is common.

Dynamics mode is often executed in time steps ranging from 0.2 to 1.0 ms. This mode is needed to study such topics as microgrid frequency control and behavior during faults and other disturbances. The Dynamics Mode modeling of storage in OpenDSS was first demonstrated by implementing a storage model developed by EDF R&D, a description of which is contained in a 2012 EPRI report [1]. Additional papers have been written on that project: references [2] and [3]. Another dynamics mode simulation is presented in this paper.

The OpenDSS Storage element model is a generic, technology-independent model intended to be suitable for planning studies (Fig. 1). It is not intended to be a specific model of any particular technology, but it should suffice for most planning studies involving one or more storage devices on a distribution system. A DLL interface is provided for those cases where it becomes necessary to model a specific storage technology in fine detail. A skilled programmer would be required to create the DLL.

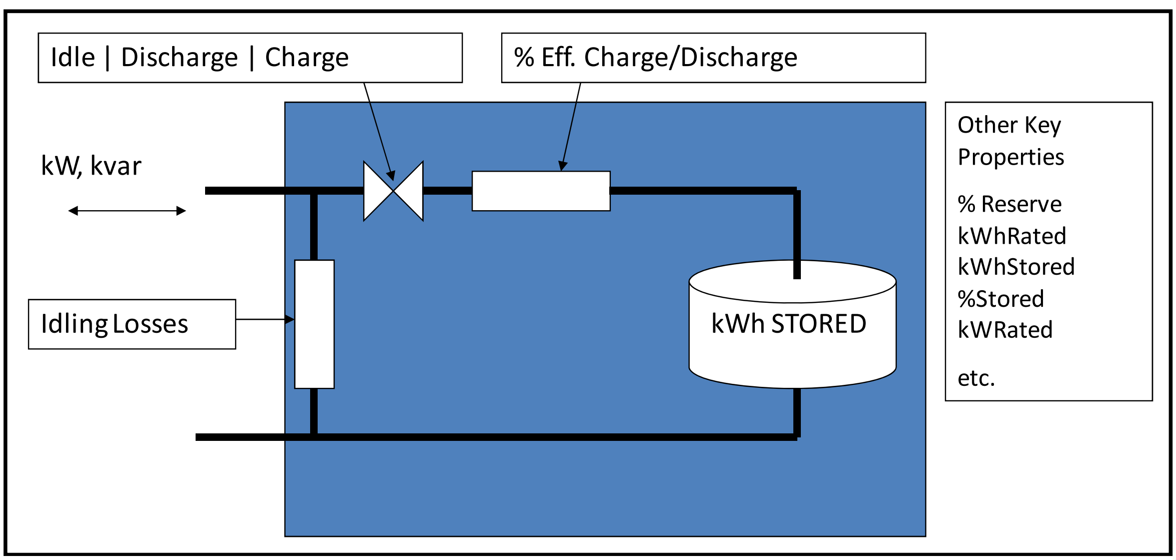

Fig. 1. Basic Concept of the EPRI OpenDSS STORAGE Model

VI. Static Analyses

The basic distribution planning analysis tool has been a static power flow. In the context of this paper, this is the capability to solve for the power flow with the storage device set to either charging or discharging at specified power values. This allows assessments of the limiting values for basic issues such as voltage rise/drop and current-carrying capacities during operation. However, it does not permit assessment of the energy storage requirement unless very simple charge and discharge shapes are assumed. The time element is not considered.

The distribution planner will be interested in studying scenarios that could conflict with normal operation. Two obvious screening scenarios are:

1. At minimum load, study maximum power output from the storage units to evaluate the potential for overvoltages during such conditions.
2. At maximum load, study the condition where the storage units are dispatched to charging mode to investigate potential undervoltages and thermal overloads.

These are two relatively simple screens that can be accomplished with most existing distribution system analysis tools. Similar screens are often performed for evaluated other forms of DER, such as high-penetration solar PV. If the storage configuration being proposed passes both tests with a satisfactory margin, the storage can likely be accommodated without interfering with the operation of the distribution system. Planners must decide what is a satisfactory margin. The screens are not comprehensive, however, and other issues may show up during sequential-time or dynamic simulations.

Another important static analysis is a short-circuit study. This requires some model of contribution of the inverter-based resources on the system to short-circuit faults. The analysis would be quite similar to that required for modeling solar PV inverter contributions. More recent research done by EPRI, has shown that inverter-based DER can be expected to contribute up to 1.2 times rated current. If the voltage sag is minor, most inverters may be assumed to continue to produce the same current as prior to the fault.

Static analysis will likely be adequate for many storage applications on distribution systems for the near term. However, when storage devices become more prevalent or large in capacity relative to the strength of the distribution system, some sort of sequential-time simulation will be required to correctly represent the operation of the storage element and the state of stored energy. Examples are described in the following sections.

VII. Capacity Evaluations

Fig. 2 shows a result from a simulation performed during EPRI's Community Energy Storage (CES) Smart Grid Demo project with AEP. [4] This simulation was designed to study the feasibility of using a number of 25 kW, 25 kWh distributed battery storage units to shave the peak substation demand load each day using energy stored in off-peak hours. The simulation was performed using actual 15-minute feeder demand data.

Just having storage available is not sufficient to guarantee that it will provide useful capacity. It must be available when it is needed to gain credit for providing capacity.

Storage is a limited resource. When the limited storage resource is used to clip the daily peak, the timing of the daily peak must be predicted accurately. In the "Load Following" control mode shown, the storage controller attempts to keep the feeder demand at, or below, the demand level at the time the storage discharge is commanded. If the storage element is triggered to discharge too quickly, the storage is depleted prior to the peak and not all the benefit from shaving the peak power on a feeder or substation transformer can be realized. This occurs on the first of the two days shown in Fig. 2.

The dashed curve shows the state of charge in the battery as it is discharged and charged over two peak-load days. The timing of dispatching the storage on the second day (the larger peak) yields a more successful result. This finding would not have been easy to determine from simple static power flows.

Notice the difference in the sizes of the areas between "No Storage" curve and the "Storage" curve during the charge and discharge cycles. The storage model represents the losses in the storage element whether charging, discharging, or idling. Losses must be represented in a simulation that captures the time-dependent nature of the problem. In this case, there is approximately a 20 % difference in the areas between the curves because the model assumed 10% losses on both charging and discharging.

The model also assumes a 1% loss when idling. This is power required to either heat or cool a battery or compensate for losses due to friction, windage, etc. in rotating storage technologies. Such a small loss does not seem like much, but it can add up over a year because the storage device is idling most of the time. This can affect the economics significantly.

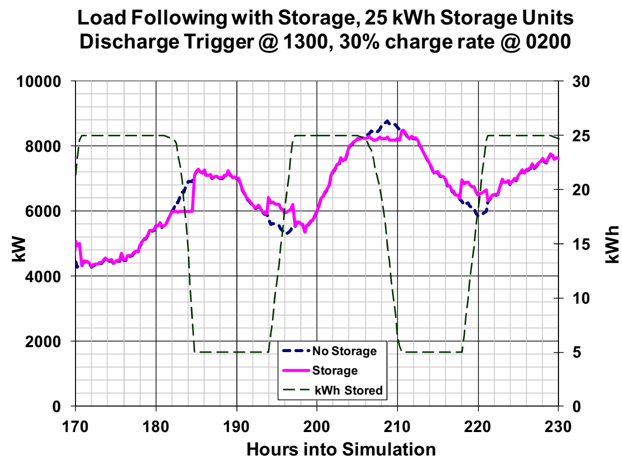

Fig. 2. Using storage for daily peak shaving

In the OpenDSS implementation of this simulation, each Storage element takes care of computing its own losses. An energy meter placed at the head of the feeder records the net effect as the simulation proceeds.

The discharge and charge states of all Storage units in this problem would be determined by a supervisory controller. There is insufficient local intelligence available for each Storage model to determine what its state should be while interconnected with the grid. Modeling controllers presents a new challenge to distribution planners because controller models can have quite complicated algorithms. In this example, discharging is started by a simple time control trigger at 13:00 each day. Then the controller manages the power dispatch of each of the distributed storage units to maintain an approximately constant demand at the head of the feeder where the controller is located. A relatively simple deadband controller with a 2 % band around the target value was used in this example.

Deadband controllers generally work well on power systems and are also generally well-behaved during simulations. Discharging continues until either the feeder demand drops below the target or the storage elements have reached their minimum allowable kWh storage level. For the CES design modeled in this simulation, reserve energy levels of 20% to 50% were investigated. The reserve requirement depends of the main application of the storage element. If the priority task is to supply customers during an outage, the amount of energy used to shave peak load must be limited.

This is another design decision a distribution planner must make that he or she may be unaccustomed to..

In the OpenDSS implementation, the storage device models manage their own storage levels and simply cease to respond to the controller when the storage is depleted to the reserve level or is fully charged.

Charging is assumed to begin at 02:00 in this example and proceed at a rate of 30% of the power rating of the storage element until the storage unit is fully charged. In this example, it takes about 3 h to recharge from a 20% reserve level to full capacity.

VIII. Storage Controllers

The OpenDSS program uses two separate models to represent storage for this kind of simulation:

1. A *Storage* element representing the device that stores energy, and
2. A "*StorageController*" element that controls one or more Storage elements using the six control modes mentioned earlier.

This is depicted in Fig. 3. The Storage element models the behavior of the storage medium and keeps track of the energy storage level, losses, etc. For the power flow solution, it acts as either a generator or a load depending on whether it is discharging or charging.

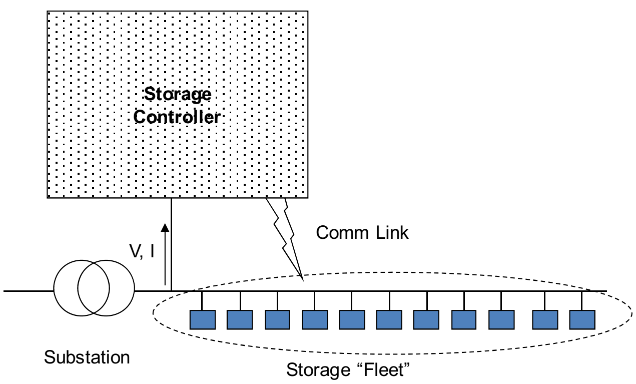

Fig. 3. OpenDSS Storage Controller Concept

The "StorageController" element neither produces nor consumes power but simply monitors a location in the active circuit and send messages to selected Storage elements to obtain the desired power from the fleet or to recharge the fleet at a suitable rate for system conditions. If the controller is monitoring a solar PV installation, the charging rate can, for example, be set to a portion of the PV output (see next section).

Separating the functionalities in the distribution planning tool in this manner simplifies the implementation in computer code. Despite this, the combination of Storage and StorageController is currently the most complicated model in OpenDSS as of this writing.

IX. Example: Compensating for Renewable Generation

Storage elements may be used for a variety of purposes on distribution systems. One commonly-cited example is to compensate for variable renewable generation. Example results are shown in Fig. 4 for a 2-MWh storage device simulated at a one-minute resolution. [5] The storage controller is programmed to charge during the peak solar PV output and then discharge at the load peak, which lags the solar output by a few hours. This helps solve a common capacity problem faced by distribution planners: solar generation output frequently falls about 2 h short of meeting the evening peak load on residential feeders, which is commonly the peak load for which distribution planners design the distribution system to deliver. Having useful storage could potentially defer capacity upgrades and allow more efficient operation of the system. Sequential-time simulation capability is required to better evaluate the true impact of such a resource on system capacity.

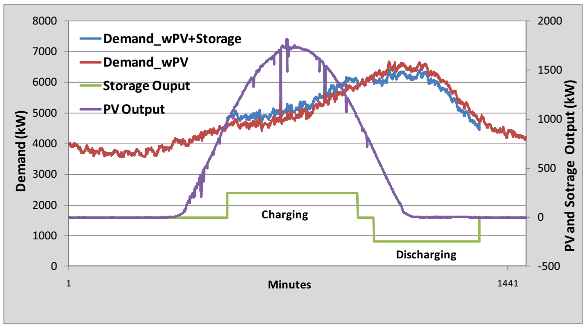

Fig. 4. Using storage to shift PV generation

In the scenario shown in Fig. 4, a time-based control (simulated with Time Mode) is used to shift the energy output from the PV to higher demand periods. While this control may be simple and cost effective to implement, it is not as effective as the Peak Shave and Load Following methods. Without direct observation, the charge/discharge durations of the time-based method must be of sufficient length to capture the expected variations in both generation and peak demand. Consequently, the discharging/charging rate tends to be shallower than may be achieved via other control methods. Furthermore, a simple time-based dispatch method performs a full discharge/charge cycle each day regardless of the energy generated or consumed.

It is important for the distribution planning tool to provide the ability to evaluate the performance of different storage control options while accounting for interaction with renewable sources. In this example, Time-based control of the storage was shown to reduce the effective energy supplied by the PV by 3.3 % due to the operational losses incurred by the storage unit each day. In contrast, a possible Peak Shave control mode was shown to decrease the effective PV generation by only 0.44 % while further reducing the peak demand by 740 kW beyond that achieved with the Time-based control.

Another storage control function commonly considered when pairing with renewable generation is smoothing the fluctuations in the variable generation. These fluctuations can result in significant voltage regulation problems on distribution systems. In fact, this is often the most significant problem limiting the PV hosting capacity of distribution systems. It is very important to have the sequential-time power flow capability to expose potential voltage regulation issues.

The net PV output with and without the matched storage is illustrated in Fig. 5 for one potential control algorithm. In this case, the energy storage is dispatched based on a moving average target for the net output of both PV and storage.

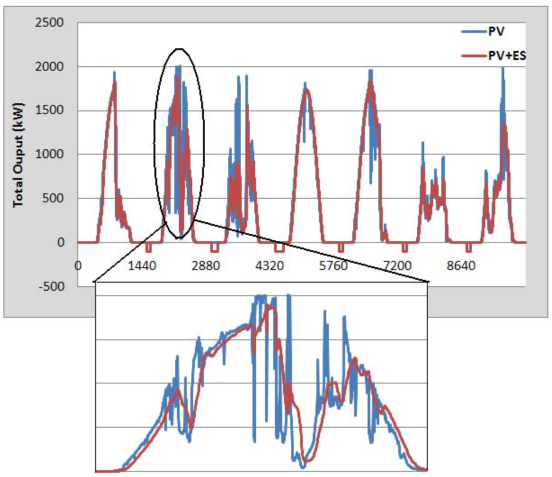

Fig. 5. Smoothing variations in PV generation

The simulation was performed in OpenDSS using the Loadshape Following mode. A *Loadshape* object in OpenDSS is simply a per-unit curve describing the variation of a quantity over time. The loadshape was derived separately using the target value while also taking into account operational constraints including the rated kWh and kW associated with the modeled storage. The loadshape derived to emulate the smoothing operation is plotted in Fig. 6.

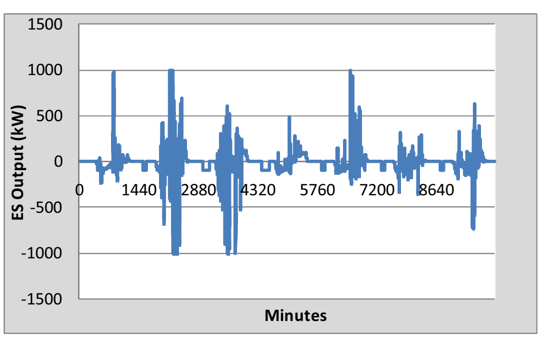

Fig. 6. Power output smoothing operation

Note that this operation requires the storage unit to alternate frequently between discharging and charging while the PV is producing varying amounts of power due to the cloud transients. The storage unit is charged to half its rated capacity at 02:00 while the PV is not producing. This allows the storage unit to absorb or inject power as needed when the PV system begins to produce power.

The charging cycle is clearly visible in both Fig. 5 and Fig. 6 . Given the variable output of the PV and the nature of smoothing functions, the amount of energy required to "top off" the storage device each evening is a direct function of the losses incurred during the previous day's operation. In this simulation, the losses incurred by the smoothing operation decreased the overall generation from the PV and storage by 1.8 %.

This illustrates the level of detail that could go into a planning study for representing schemes to smooth PV output. The Loadshape mode is quite useful for analyzing this because the planner needs flexible power shape modeling capability for this kind of problem.

X. Example: Dynamics Simulation

Most of the other time-varying simulation modes identified here can be executed by supplying the load and storage power charging/discharging characteristic using power data in time steps ranging from a few seconds to one hour. Then the analysis tool must simply perform a series of power flow solutions, which is generally an extension of the single snapshot power flow solution supported by nearly all distribution system analysis tools. This assumes the time step size is longer than the transients within the storage element or control.

However, to study the interaction of inverter-based storage devices during disturbances or for such things as frequency and stability control on microgrids requires dynamics, or *electromechanical transients*, analysis capability to simulate storage in very small times steps of 1 ms, or less. The development of models suitable for distribution planning is still very much in the embryonic stage and continues to be an active research topic at EPRI.

The simple Dynamics mode implemented within the OpenDSS software was originally intended to model rotating machine dynamics for islanding analysis sufficient to evaluate a proposed distributed generation (DG) interconnection against the frequency and voltage requirements of IEEE Std 1547™. It is the only mode of OpenDSS that implements the solution of differential equations. For rotating machines, the differential equations represent the so-called "swing equation" for each machine. For inverters, the differential equations would represent such things as proportional-integral (PI) control loops, which can be quite complex.

OpenDSS provides the dynamics simulation mode to cover these kinds of scenarios; however, it is also possible to include customized models to interact with the simulation in this simulation mode. By using the COM interface provided with OpenDSS users can include their own models using their preferred programming language.

To illustrate this topic a customized model for a storage is implemented, this model combines the Thevenin equivalent of a battery cluster and an inverter that is controlled using a PI controller [7]. The aim with this storage model is to simulate a black start after an event to supply a MV microgrid. The test system used is the familiar IEEE 13-node Test Feeder, where opening the recloser between nodes 671 and 692 creates an island with a total demand of 1MW (unbalanced). The proposed system is shown in Fig. 7.

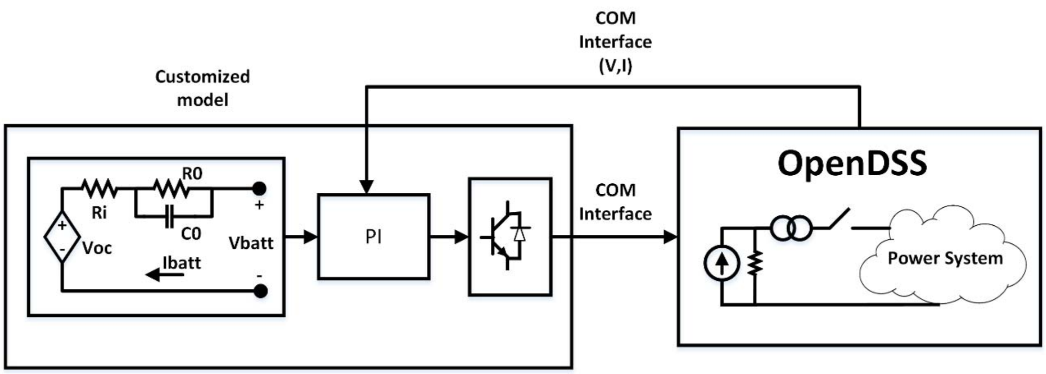

Fig. 7. Proposed simulation including a customized model

According to the Thevenin model of the battery cluster shown in Fig. 7 the output of the battery can be obtained as follows:

$$V_{batt} = V_{OC} - \left(R_i + \frac{K}{SOC}\right) I_{batt} \qquad (1)$$

Where K is the polarization constant (typically 0.1Ω) and SOC is the state-of-charge of the battery [8].

The black start of a portion of the MV distribution grid is an operation performed after the interruption of power to the network. For example, after a fault the protection scheme trips forming a MV island. The black start is executed in two stages: a) the starting of the DC/AC converter connected to the storage in no-load condition and then b) closing the MV breaker to energize the MV island [9]. Both operations are coordinated from the customized storage model, which is implemented using NI LabVIEW.

The inverter is modeled based on a normal OpenDSS voltage source model (Thevenin equivalent) and the controlled parameter is the per-unit voltage. The customized model considers SOC, the supplied power and current of the storage device. This simulation is performed using the dynamic mode with a time step of 4ms. The results of the simulation are shown in Fig. 8.

As can be seen in Fig. 8, the system remains off for 2 seconds after the fault event. Then the controller starts the DC/AC converter of the storage element. At this moment, the batteries are fully charged and can provide a total power of 2.4 MW and the only consumption is due to the internal losses of the storage model. After 4 more seconds, the MV breaker is closed connecting the MV microgrid and there is a voltage drop of 0.17 pu as a consequence of the load connection supplying the power shown.

At this point the PI controller starts correcting the voltage and finally reaches the specified voltage (2.4kV) after 2.5 seconds (8.5 seconds of simulation) and starts to deliver power to the connected load in a controlled way. When the fault is cleared, the utility controller communicates the restoration to the local microgrid supplier (the storage) to start the reconnection procedure. After this procedure, the behavior of the storage device changes from producer to consumer, entering into the charging state.

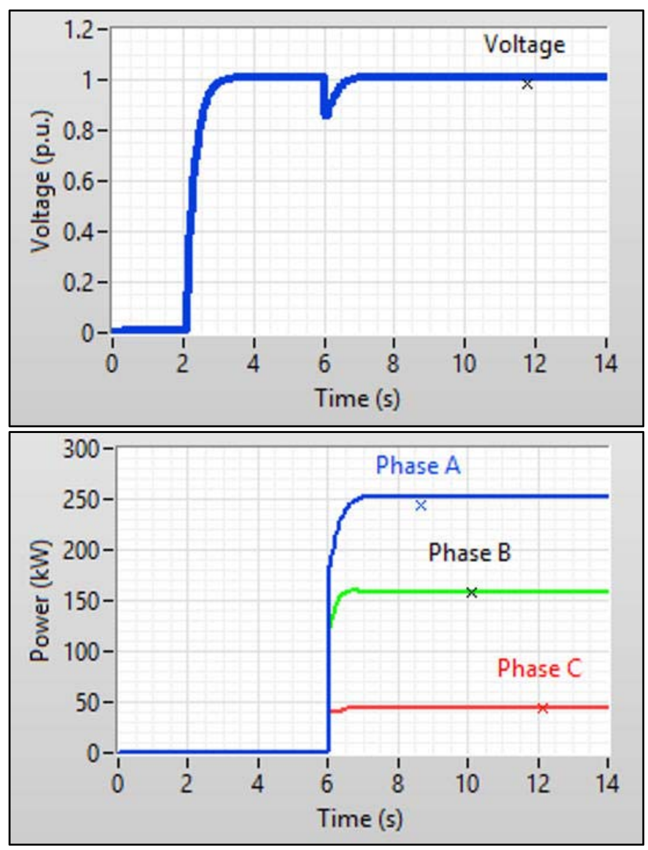

Fig. 8. Results obtained when performing a black start operation on a MV microgrid

This is an example of how customized storage models can be integrated into the simulation in a distribution system analysis program with dynamics solution capability. The presented model is a very simple model, but is very useful to illustrate how the variables of a model implemented using an external programming language (Labview) can be used in co-simulation with OpenDSS. There are some other technical issues that must be considered in terms of co-simulation performance, which are documented and can be consulted by users when the performance becomes critical [9]

XI. Vendor-Supplied Model Interfaces

The modeling complexities described above for dynamics analysis are likely too onerous to be practical to include in the typical distribution planning process. One such model the authors have developed required obtaining values for 31 variables. There is insufficient time in the planning process to build and calibrate such models for potentially numerous different storage devices.

A commonly-proposed solution to this problem is for manufacturers of the energy storage systems to supply the models for planning software along with the equipment. This seems like a good idea, but is not necessarily very easy to implement. Among the issues that must be dealt with are:

- The establishment of a common software interface between the distribution system analysis packages and the vendor-supplied models.
- The interface would have variants for quasi-static power flow, dynamics, and electromagnetic transients; each can have different modeling requirements. Standard-setting working groups would have to be established to develop the interface specifications.
- Although Microsoft Windows is the dominant platform for distribution planners in the US, the interface might have to also be implementable on various computer platforms such as Linux, OS/X, and possibly handheld platforms such as Android and iOS.
- Distribution system analysis software vendors will have to implement a means of supporting the interface in their software product.
- Storage system suppliers will generally want some means of protecting the proprietary design of their product. This will generally rule out open-source models and require compiled libraries (DLL, SO, etc). This is not a fool-proof method of protecting the intellectual property due to the existence of software for reverse engineering such libraries.

So there are quite a few development steps to be taken before this idea can become a reality. In the meantime, research continues into simplified methods.

XII. Conclusions

Sequential-time power flow simulation is a relatively simple extension of the typical static power flow solution in common distribution system analysis tools. Each of the sequential-time simulation modes presented in this paper requires more sophisticated models and more data than a simple static power flow evaluation with which most distribution planners are familiar.

Dynamics models of inverter-based storage may require values of more than 30 parameters. This is daunting for distribution planners. Some form of standard model framework for vendor-supplied models must be developed to make this task easier and more attractive for distribution system analysts. Substantial model development work for distribution system analysis tools remains.

Lacking these advancements, the distribution planner will be forced into a default position of building systems with greater power delivery capacity to handle energy storage wherever it appears. A similar problem exists with hosting widespread solar PV generation. If the proposed system fails either of the two simple tests proposed at the beginning of this paper for static mode solutions, the planner has the choice of either reinforcing the system so that it can accommodate the proposed system or declining the interconnect it. Like DG interconnections, this would move the proposal from a fast-track interconnection process to one requiring detailed studies to determine interconnection requirements.

Another area of concern among distribution planners is related to reliance on high-speed communications for controlling microgrids, multiple storage devices, and other fast-acting distributed resources. It is a legitimate question as to whether or not the latency of the communications network will be a major roadblock to implementing many of the ideas for storage controllers – especially those applications requiring high-speed response to frequency changes and power ramping. The capability of a distribution planning tool for this would have to include some model – perhaps simplified – of the ICT network as well as the power network with its controllers. Work on this has only just begun and it is still very unclear as of this writing what will be a suitable form of this capability for distribution planners.

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