THE NEED FOR OPERATIONAL PLANNING IN SMART DISTRIBUTION GRID USING NEAR REAL-TIME NETWORK SIMULATION

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ABSTRACT

The new challenges in the future distribution system, such as Distributed Energy Resources (DER) integration, micro-grids and virtual power plants, have created the same demand for system simulation studies for the distribution system as we have for the power transmission system. The former concept of "connect and forget" for DER integration will no longer work with the interconnection of renewable DER such as photovoltaic (PV) and wind generation. Additionally the integration of Electric cars (E-cars) to the distribution systems complicates the situation. The integration of high penetration levels of DER can greatly affect the traditional and conventional methods of distribution system planning and operation. In this paper we present the concept of operational planning using near real-time network simulation with an example test system case study representing the future smart distribution grid.

INTRODUCTION

The primary challenge in the case of a future smart distribution grid is the intermittent nature of DER output on an hourly, daily, and weekly basis. PV generation and wind generation have, for the most part, an inverse generation dispatch relationship (i.e. typically wind generation picks up during the evening and early morning; PV dispatches during the daytime when there are sun rays). Another interesting challenge is the control of E-cars charging and discharging simultaneously, as other DER vary, over a period of time. These issues will have major effects on the development of the future distribution system infrastructure and configuration.

The concept of near real-time operational planning for a smart distribution grid is based on the ideology that besides the restructuring of the distribution grid, near real-time operational planning data just prior to the time of operation will enable optimal operation of the smart distribution grid. The fundamental criterion in this method is to evaluate the distribution system operating conditions on a near real-time basis.

The smart meter delivers the required near real-time short interval load and generation data/profiles; this will provide the distribution planning engineers with useful information required to perform a distribution system simulation using a distribution system analysis simulation software in near real-time.

WHY CONVENTIONAL DISTRIBUTION PLANNING METHODS MAY NOT WORK

The most significant change for an existing distribution system in the making of smart distribution grid is that distribution systems may not have been designed to accommodate two-way power flow, which is the most important factor after the integration of DER to a distribution system. Traditional distribution planning techniques may need to be modified to effectively account for impacts of DER. Some of the salient aspects that arise in planning and operations with the integration of DER are given below [1]-[2].

- The steady state and transient behaviours of the distribution systems have to be analyzed using a robust distribution system analysis simulation tool in accordance with the generation interconnection guidelines of distribution utilities
- Distribution transformers and lines/feeders may have to be upgraded depending on the location and size of DER
- PV and E-cars connected at the customer side may or may not be owned by distribution utilities and hence need to be accounted for carefully in planning studies
- Wind and PV have completely different generation profiles and hence have to be coordinated with the rest of the generation and load profiles
- E-cars can be realized as distributed storage and need to be analyzed carefully

In the near future, the major challenge that distribution system planners will have to address is the accommodation of E-cars, which will significantly impact the load profile in the distribution system [3]-[5].

ROLE OF SMART METERING IN NEAR REAL-TIME DATA ACQUISITION

The role of smart meters is the most vital for near real-time data acquisition. Presently, obtaining metered data in 15 minute intervals from smart meters (single or aggregated) is targeted by most of the distribution utilities. Hence in this paper, "near real-time" corresponds to prior 15 minute intervals. If the smart meters are able to efficiently obtain metered data in near real-time, then this facilitates some of the major applications like demand response, customer participation, DER dispatch control, smart switching within distribution feeders, etc. Also, effective utilization of distribution system equipment may be achieved as near real-time utilization of distribution lines and transformers, and voltage at several points are known.

THE CONCEPT OF NEAR REAL-TIME OPERATIONAL PLANNING IN THE SMART DISTRIBUTION GRID

Near real-time operational planning is a method of evaluating the distribution network through simulations on a prior 15 minute interval basis by using the metered data of load and generation profiles obtained from the smart meters. The distribution system simulations need to be performed using a distribution system simulation software tool which has the capabilities to represent the DER models accurately, to perform optimal network reconfiguration schemes, and to implement optimal protection schemes.

The load/generation profiles are directly exported to the distribution system simulation software in near real-time intervals, which enables a distribution planner to have a near real-time distribution system simulation model for operational planning. The results obtained after running the system simulations provide very detailed information on the system conditions (like element utilization, loadings, system losses, voltages, etc) in 15 minute intervals. The distribution system dynamic and transient stability simulations may also be performed in order to ensure stable operation of the systems. Hence the near real-time operational planning technique provides the necessary information to the distribution system engineer to make decisions facilitating optimal operation of the smart distribution grid.

EXAMPLE TEST SYSTEM: DISTRIBUTION SYSTEM OF A PART OF A DISTRICT IN ERLANGEN, GERMANY

In order to better illustrate this concept, we used PSS®SINCAL to model an example test distribution system of part of Büchenbach, an urban district of Erlangen, Germany. The distribution system represents a three-phase, 50 Hz, radial system with 20 kV primary voltage level and a 400 V secondary voltage level. The distribution system consists of a primary substation with three distribution feeders (Feeder 1: blue; Feeder 2: red; Feeder 3: green) as shown in Figure 1.

The example test system was modified to represent a near future smart distribution grid with considerable DER penetration. Each feeder consists of different load profiles and DER generation profiles. The detail of the system modification and the system description is explained in the following paragraph.

Feeder 1 (blue) consists of 527 residential customers (class A) with a total feeder coincident peak load of 2.13 MW. DER availability in Feeder 1 is PV generation, with an installed capacity of nearly 3 MW consisting of thirty one 65 kW customer owned installations and three 350 kW utility owned installations located at different sections of the feeder. Feeder 2 (red) consists of 457 residential customers (class B) with a total feeder coincident peak load of 2.63 MW. This feeder consists of 20 E-car charging stations with 5 charging points per station. Each charging point is rated 400 V, 25 A. Feeder 3 (green) consists of 263 commercial customers with a total feeder coincident peak load of 1.4 MW. DER availability in this feeder are 3 wind generators of 600 kW each with a total of 1.8 MW.

Figure 1: Example Test Distribution System (Part of an Urban District in Erlangen, Germany)

The summary of the load profiles and DER availability in the feeders are shown in Table 1. The load profiles for all 3 feeders for a 24 hour period are shown in Figure 2 and the 24 hour generation profile for the same day for PV and wind generation in Feeder 1 and Feeder 3 respectively are shown in Figure 3. These profiles can be obtained from smart meters on a 15 minute interval. Figure 4 represents the layout of the near future smart distribution grid developed as a result of modifications made to the example test distribution system.

Table 1: Summary of Loading Profiles and DER Availability

Feeder ID	Feeder Loading Profiles	Feeder DER Availability
Feeder 1	Residential Class A	Photo Voltaic Generation
Feeder 2	Residential Class B	Plug in Hybrid Electric Vehicles
Feeder 3	Commercial	Wind Generation

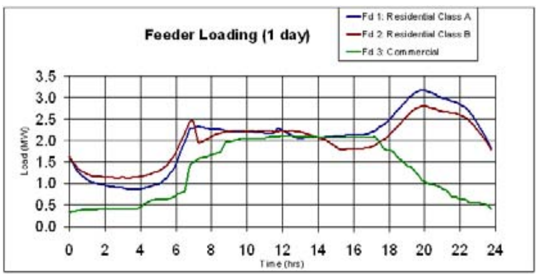

Figure 2: 24 Hour Load Profile of the 3 Feeders

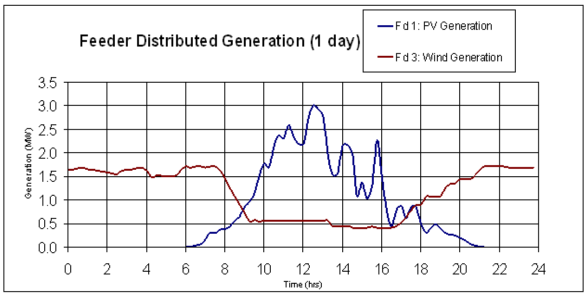

Figure 3: 24 Hour Generation Profile for Feeders 1 and 3

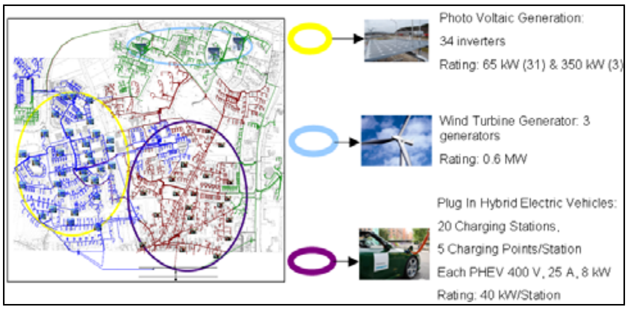

Figure 4: Modified Example Distribution Test system: DER Penetration in Future Smart Distribution Grid

ILLUSTRATION OF THE NEAR REAL-TIME OPERATIONAL PLANNING CONCEPT ON THE TEST SYSTEM

The concept of near real-time operational planning is illustrated as shown in Figure 5. The 15 minute interval data across all the individual meters located at various load and supply points of the distribution system are collected and processed using Meter Data Management (MDM) platform software. The load profile and generation profile database can then be exported instantly to a database oriented distribution system simulation software tool (like PSS®SINCAL as shown in the Figure). Once the operational model in PSS®SINCAL, system simulations can be performed to evaluate the conditions of the present system in near real-time. With the 15 minute measured data in addition to the historical and short term forecasted load and generation profiles, it is possible to run system simulations to evaluate the state of the distribution system for the following hours and days in a 15 minute interval.
According to the proposed concept, a 3 day series of load flow simulation with 15 minute intervals is carried out assuming that the historical and present near real-time measured data are updated to distribution system simulation software tool from MDM software. The 24 hour load profile is assumed to remain the same for each day, indicating 3 similar days in terms of weather and other factors. In reality, when implementing the concept on a real system, the historical and near real-time metered data will be used for the short term load forecast to predict the future hour's load profiles.

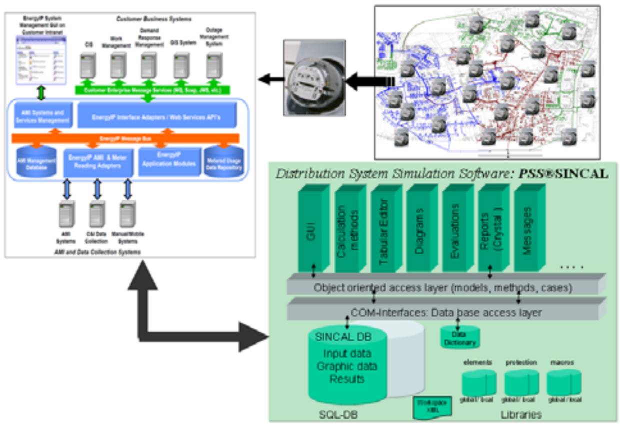

Figure 5: Illustration of Near Real Time Operational Planning Concept

The generation of a profile of the DER in the smart distribution grid is the most challenging aspect as the three types of DER present in this example system have different dispatch and intermittency characteristics. We assume a near future realistic scenario for DER dispatch in each feeder for the 3 day period. The PV generation in Feeder 1 is assumed to be nominal during day 1 and day 3, but day 2 is assumed to be a cloudy day. The wind generation in Feeder 3 is assumed to be nominal during day 1, high during day 2 and no wind during day 3. The E-car charging is assumed to represent smooth charging during day 1 (i.e. each E-car connected constantly charges with 8 kW, 400 V, 25 A in 4 hours from 10 pm to 2 am); smart charging is assumed during day 2 (i.e. the E-cars charge intermittently all night and retain their full charge); and the concept of smart charging, energy storage, peak smoothing is assumed during day 3 (i.e. the E-cars feed back power to the grid and also charge intermittently all night to retain full charge). The summary of the generation profile scenarios is presented in Table 2 below. Figure 6 shows an individual E-car charging and discharging profile over the period of 3 days. Figure 7 shows the load profile (dotted lines) and generation profile over a period of 3 days.

Table 2: DER Dispatch Scenarios: 3 Days

Year 2011	Feeder 1	Feeder 3	Feeder 2
Day 1	Nominal PV	Nominal Wind	Smooth Charging
Day 2	No Sun	High Wind	Smart Changing
Day 3	Nominal PV	No Wind	Smart Changing + Energy Storage + Peak Smoothing

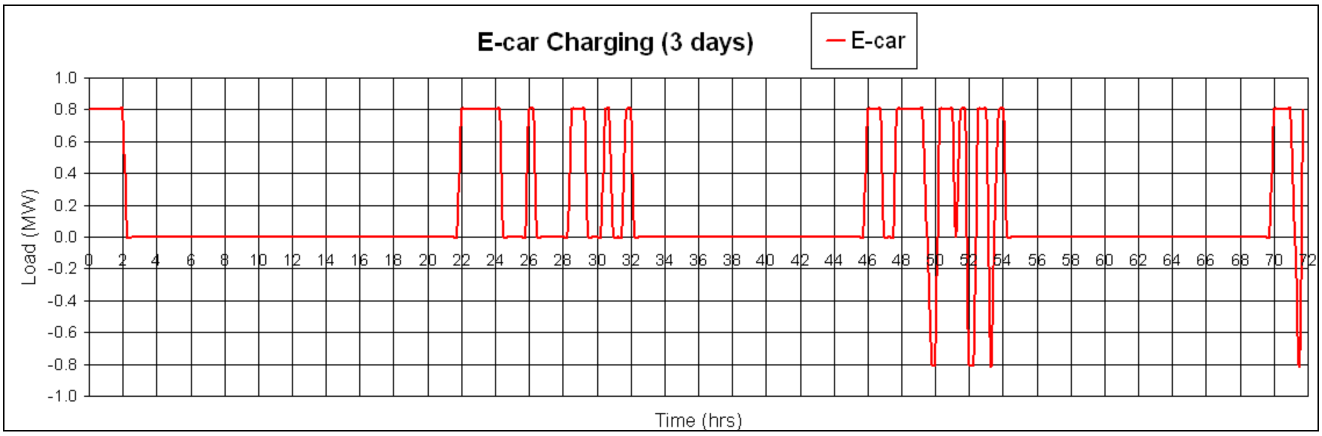

Figure 6: E-Car Charging and Discharging Profile: 3 Days

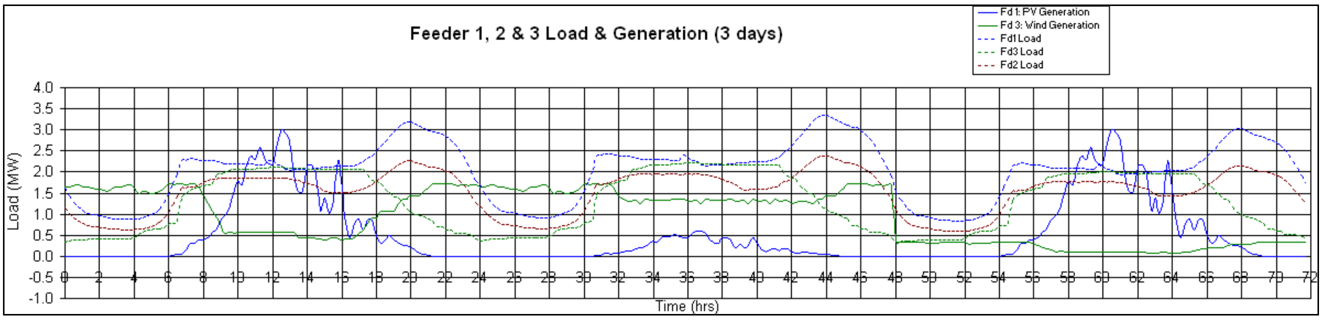

Figure 7: 3 Day Load and Generation Profile of the Example Smart Distribution Grid

Load flow simulations were run for a 3 day period with a 15 minute interval in order to evaluate the system conditions and to plan for necessary operational actions for the 3 days. The resulting load density contour diagram at various times of the day during day 1 are shown in Figure 8; during day 1 the load across the distribution system does not seem to vary considerably. The resulting voltage contour diagrams at various times of the day during day 1 are shown in Figure 9; during day 1 the intermittency characteristics of wind and PV generation can be observed to vary considerably. Voltage variations across the distribution system at different times of the day are quite noticeable.

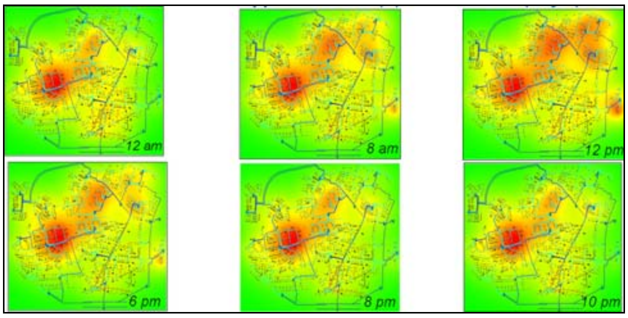

Figure 8: Contour Diagram of Load Flow Apparent Power during various times (Day 1)

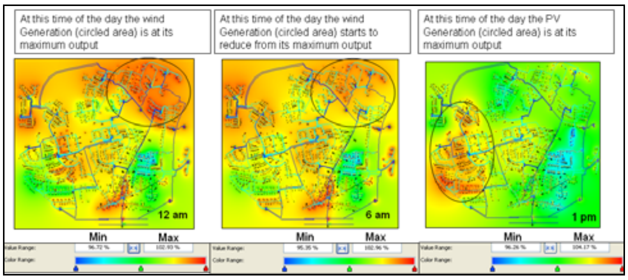

Figure 9: Contour Diagram of System Voltage during various times (Day 1)

In this example case study, smart switching between feeders in order to minimize back feeding to the transmission grid was the main focus. The smart switching has to be performed based on the system criteria that the system should operate within the voltage and the thermal loading constraints from a steady state point of view. The smart switching scenarios can be evaluated by performing further load flow simulations on the system and the best solutions can be considered for implementation. For the example system under consideration, a smart switching scheme shown in Table 3 is proposed to be applied over a period of 3 days based on the switching points available between the feeders in the distribution system as shown in Figure 10. The switching points define the level of load transfer between the feeders. This scheme may also be subject to change according to the near real-time measured data which will be updated every 15 minutes. Hence a distribution system planner can make decisions on the smart distribution grid operations on a short term basis to ensure optimal grid operations.

Table 3: Smart Switching Scheme

Year 2011	Load Transfer	Time	Load (MW)
Day 1	Fd 3 to Fd 1	0:00 to 7:45	Based on Switching
	Fd 1 to Fd 3	12 to 13:15	Based on Switching
	Fd 3 to Fd 1	19:30 to 24	Based on Switching
Day 2	Fd 3 to Fd 2	0:00 to 7:30	Based on Switching
	Fd 3 to Fd 2	19:30 to 24	Based on Switching
Day 3	Fd 1 to Fd 2	12 to 13:15	Based on Switching

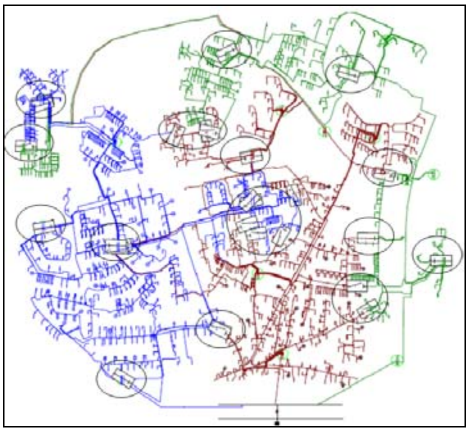

Figure 10: Contour Diagram of System Voltage during various times (Day 1)

NEAR REAL-TIME OPERATIONAL PLANNING CONCEPT FOR SYSTEM STABILTY EVALUATION

The high penetration of intermittent DER in any smart distribution grid would cause complexity in system stability. The concept of near real-time operational planning can be employed to evaluate the dynamic and transient stability conditions of the distribution system. The aspects of smart switching and variable renewable DER dispatch are the main factors that would impact the stability of the system. Hence stability simulations would become an integral part of planning for a future smart distribution grid and performing these simulations using the near real-time operational planning method would enable efficient operation of the smart distribution grid.

CONCLUSION

The concept of near real-time operational planning was proposed and illustrated using a real example distribution system modified to represent the near future smart distribution grid. The smart switching scheme for a 3 day period for the example smart distribution grid was proposed using this concept. This paper also emphasized the challenges that arise due to integration of various types of DER at different penetration levels at various geographical locations in the example distribution system, and proposed the effectiveness of the approach of using near real-time operational planning to overcome this challenge.

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