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Dynamic Non-Wires Alternatives Integration Within Distribution System Planning

D. MONTENEGRO, J. TAYLOR
Electric Power Research Institute
USA

SUMMARY

This paper introduces a dynamic technique for non-wires alternatives (NWA) integration in power distribution systems planning. With this technique, planning studies can be highly detailed for evaluating the benefits of integrating NWA for reinforcing the distribution system, visualizing their effect on nowadays and future scenarios. Multiple technically viable paths are generated as the result of combining different technologies for successfully completing the planning study without thermal or voltage violations, within the time range defined by the planner. These paths can then be sorted according to their economic cost to obtain the best investment plan for the next years based on the load growth forecast, the technologies used to relieve the power distribution system and the study's objectives. The results obtained through this planning technique helps utilities identifying new business models, directions and opportunities when integrating non-traditional technologies into distribution planning.

KEYWORDS

Distribution planning, Power Distribution, Power System Analysis, Power System Simulation, Smart Grid, Time Series Analysis.

dmmartinez@epri.com

INTRODUCTION

Planning studies are an essential component for ensuring cost effective and timely distribution system upgrades and expansion. Traditionally, planning studies are based on load flow simulations representing the instantaneous peak demand projected for one to five years into the future. As the traditional alternatives were passive in nature and tended to provide a significant increase in capacity, short-range planning studies generally only considered a fixed planning horizon of one to five years in the future. In some cases, the resulting expansion plan may be evaluated against long-range planning horizons; however, there was no need to evaluate whether a decision would be viable or cost effective considering the years immediately following its implementation.

A significant change occurring across the industry is an increased focus on the emerging technologies that may be able to offset the need for expensive system upgrades and help meet other system objectives. These non-traditional solutions, referred as non-wires alternatives (NWAs) [1], while not necessarily altering the overall planning process, are expected to increase the complexity of the simulations and studies needed [2]. As most NWA are active in nature – due to the reliance upon variable or constrained energy sources as well as advanced controls – they intrinsically introduce new dynamic characteristics that need to be accounted for within distribution planning studies.

NWA introduce dynamics that influence the planning time horizon. Depending upon the design, some NWA may defer the need for subsequent upgrades for a year or more. Conversely, some NWAs are modular in nature and can be incrementally added to match the system needs at a potentially lower capital cost after the initial investment.

The expected operational lifetimes of these emerging technologies also tend to be shorter than most traditional solutions and should be appropriately accounted for the in the calculation of costs, if not directly through load-flow simulations, other assessment techniques. The identification and evaluation of multiple potential future alternative deployment options, occurring in different years and comprised of different alternative types, is necessary to fully assess and compare NWA to traditional solutions.

The power system planning tools and techniques require to provide a framework for harmonizing the new technologies so interconnected systems can be automated, simultaneously operated and visualized for maximum grid benefit by distribution engineers. These needs require analysis techniques and tools to consider the time-changing features of distribution systems when including new technologies for planning studies.

This paper introduces a multi-dimensional planning technique for NWA integration in power systems. With this technique, planning studies can be as detailed as needed for integrating new technologies to visualize their effect on the current and future distribution system. The multiple dimensions generated corresponding to viable technical solutions, can be compared economically to obtain the best investment plan for the years ahead based on the load growth forecast, the technologies used to relieve the power system and the circuit model used for the planning study. This paper only discusses the technical analysis, leaving the economic analysis for subsequent papers.

This paper is organized as follows: First, introduces the features of NWA and why they need to be addressed in planning studies. Second, an introduction to the multi-dimensional planning technique is presented. Third, it presents a study case to finalize with the conclusions.

NON-WIRES ALTERNATIVES

NWAs are progressively being considered by distribution and transmission planners for economically addressing acknowledged grid limitations. Gaining popularity due to technological advancements, falling costs, and supportive regulatory orders, regulators in several jurisdictions are now mandating that utilities evaluate the feasibility of DER-based alternatives prior to conducting any major grid reinforcements [1].

But while NWAs present opportunities for distribution and transmission planners, they have a significant impact on the complexity of the planning process and pose new challenges to associated analytics, tools, and business processes [3]. Traditionally, utility electric power systems were not designed to accommodate NWAs such as distributed generation (DG) and storage at distribution level. Adding DG and energy storage (ES), among other NWAs, will change the system response in some manner. A major concern about integrating NWAs is due to their variability on time. Compared to their predecessors, NWAs are not suitable for energy generation constantly since they depend on variable weather conditions and other factors depending on the technology used.

A good example of this are photovoltaic panel arrays (PV), are highly dependent on the amount of sunlight and temperature they are exposed to. Fig 1 presents 3 different irradiance profiles for 3 different days. These represent the sunlight incidence in clear, variable, and overcast days for the daily operation of PV. As can be seen, not all days have the same irradiance, resulting in a variable energy production from PV.

Similarly, ES is an element that changes its electrical behavior depending on its State of Charge (SoC). When the SoC is within an acceptable range, ES will act as DG if required.

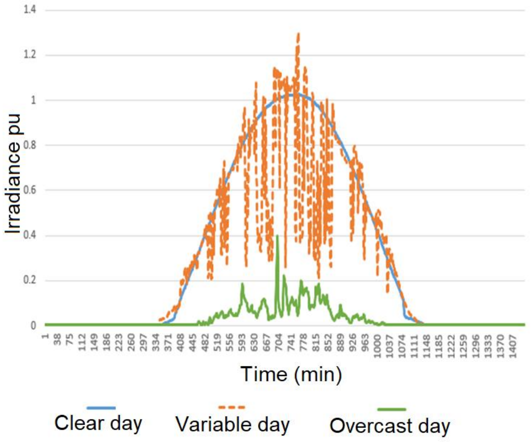


Fig 1. Solar irradiance profiles for PV

But the energy stored in the ES is not unlimited, requiring ES to recharge contributing to increase the power system loading during the charging period. Analogous to the cases mentioned, other NWAs variability will affect the normal power distribution network at different points in time, requiring a deeper analysis to verify their effects during a planning study.

Quasi-static-time-series (QSTS) simulation is a tool used for assessing the system response over time and has found wide acceptance across the industry. Furthermore, it can serve as the basis for designing and assessing the technical feasibility of proposed NWA implementations[4, 5], advancing traditional planning studies to consider emerging technologies and planning practices.

QSTS simulations propose an accurate framework for evaluating the influence of NWAs in the distribution network, incorporating the variable performance of NWAs it makes easier to confirm their impact when assessing a planning problem; impacts that cannot be evaluated accurately by using traditional planning studies.

DYNAMIC ALTERNATIVES PLANNING

As mentioned above, there are needs and tools for analyzing the impact of NWAs in the distribution system. This section describes how these needs and tools are brought together for planning studies. A planning horizon comprehends several years in which the power system loading varies representing new customers and the grid expansion. In many cases, this growth triggers thermal and voltage violations in time that need to be addressed year by year. Conventionally, to mitigate these violations distribution planners propose equipment upgrades and the addition/adjust of passive and regulating devices across the power system. These tasks can be performed in one or several years ahead depending on the utility's investing interests. In the planning study, it is expected that the combination of different technical alternatives in time will reveal the best investment criteria for the years to come, which is validated through an economic analysis.

Adding NWAs to the equation increases the number of possible combinations for the planning study, highlighting the importance of a method to identify and map these scenarios efficiently during the study. The method proposed in this paper is a graphical framework for describing the relationship, progression, and dependencies between the power system state through time and the alternatives needed to solve the violations found during the analysis period.

The proposed method, which the authors called the Doc. Brown Tree (DBT), agrees with all the characteristics of a directed graph. The cumulative nature of the deployed alternatives can be defined within the graph as the dependency between edges. This means that for evaluating an edge all its predecessors need to be evaluated first [6, 7]. For example, if a graph S contains edges A, B, C, D as follows:

$$S = (A, B, C, D) \tag{1}$$

And the transitive relations between the edges (link branches) are defined as:

$$R = ((A, B), (A, C), (B, D)) \tag{2}$$

It can be inferred that A depends on C and B, consequently B needs to be calculated before A. C and D are given. This way, the dependency graph used to describe this case will be given by:

$$G = (S, T) \tag{3}$$

Where T being the transitive reduction of R. This definition is intended to describe the relationship between an edge and its predecessors when evaluating the possible solutions for a system violation in a year under study. To explain this concept let’s assume a time horizon of 10 years for a planning study. The system is assessed on a yearly basis and any identified impacts are sufficiently mitigated using the correct alternative. These investments are assumed to be deployed in the system the year associated with the identified need and are cumulative over the study period. An alternative implemented in the first year will remain in place in the analysis of all the subsequent years in the same timeline.

To create the reference timeline, the analysis will start at year one and try to solve all the violations within the 10-year period using any combination of methods. The goal is to create a timeline in which all the system needs have been identified and successfully mitigated. This will create a reference that can be described as a graph, where the edges are the years in which a violation was solved, and the link branches are the method used to solve the violation at the origin edge (year). The years where no violation was reported will not be included in the graph

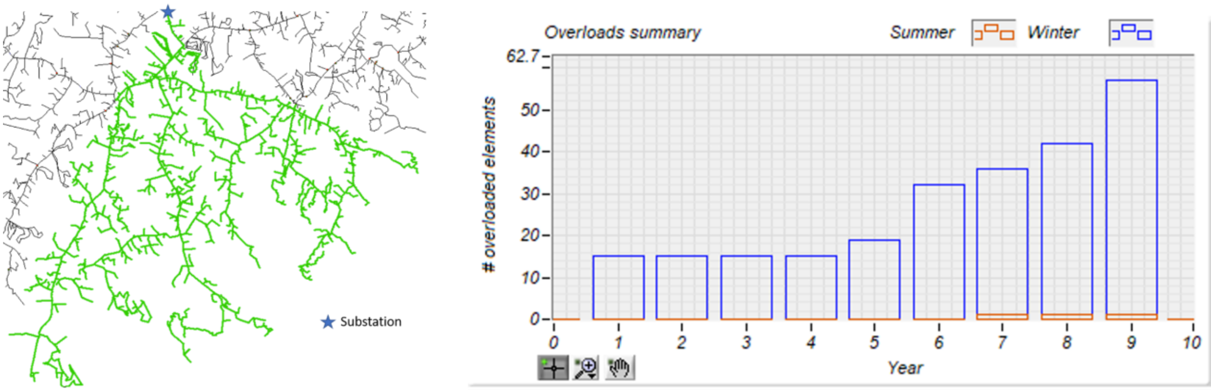
The new reference timeline can be used to return to years in which a relieving action was required and explore a different alternative, which will create a new branch in the graph located at the same edge and resulting in a new possible future path to year 10. All the new combinations coming the critical points on each deployment path create a directed. Graphing the timelines in this fashion provides the ability to easily track and return to critical points where additional alternatives may be considered, as well as provides consistency between other deployment scenarios sharing a common set of past system changes.

STUDY CASE

The DBT method is implemented within the Automated Distribution Assessment Planning Toolset (ADAPT) tool, which is currently developed by EPRI for proposing the next generation of planning practices and tools. This tool uses OpenDSS for simulation purposes, and the DBT for navigating through the different timelines created during the study. Consider the feeder shown at Fig 2a. The model of this feeder contains the forecasted load growth for 9 years, which is provided by the utility, as well as all the controls already deployed across the circuit such as regulators, capacitor banks and existing DG. for the study, the utility also provided the seasonal ratings (winter and summer) for the lines.

After pre-screening the feeder for the 9-year period, the thermal violations have been identified as shown in Fig 2b. As can be seen in Fig 2b, the feeder is a winter peaking feeder, revealing that most of the violations take place during the winter period. The feeder has a peak demand of 4.57 MW and 1.3696 Mvar in year one. The features and the alternatives to be used for the study are presented in TABLE 1. For this example, only 4 alternatives will be used: 2 traditional (reconductor and load transfer) and 2 NWAs (ES and PV).

The use of ES for relieving violations is limited to 2 sizes available for the utility. The number of sizes and the features of ES can be modified as needed for the study. For adding PV during the study, a maximum limit of PV penetration has been stablished. This limit is expected to reflect the feeder's hosting capacity study previously performed.



a) b)

.Fig 2. a) Feeder under study (highlighted in green), b) Pre-screening results for the proposed feeder

Alternative	Feature name	Size
Reconductor	New ampacity	628 A @ summer 924 A @ Winter
Load transfer		1.4 MW
ES	Sizes	2 MW @ 4 MWh 2MW @ 8 MWh
PV	Max allocation per year	4 MW

TABLE I. ALTERNATIVE FEATURES FOR THE STUDY

A. *Study results*

After conducting the study, a total of 229 different valid technical combinations were found, an extract of the results report is shown at Fig 3. In Fig 3, the alternatives colored in grey are the ones that failed to solve the proposed violation for the current year. The other colors highlight alternatives that successfully solved the problem at the year and allowed the analysis to move into the subsequent years. The effectiveness of the alternatives used, given the feeder features, can also be obtained by navigating the DBT.

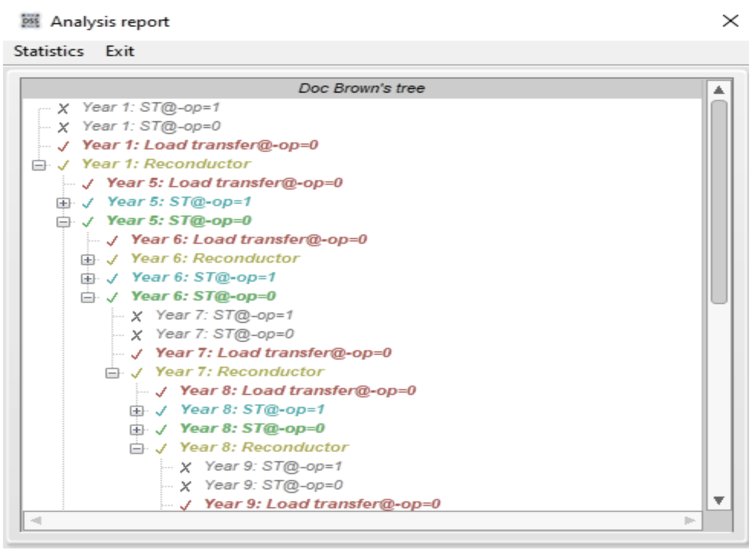


Fig 3. Analysis results for the study case

For the case presented in this paper, the load transfer solves all the violations for the year in which it is applied and the years to come. This is possible due to the load transfer size and the availability of an adjacent feeder for hosting the load.

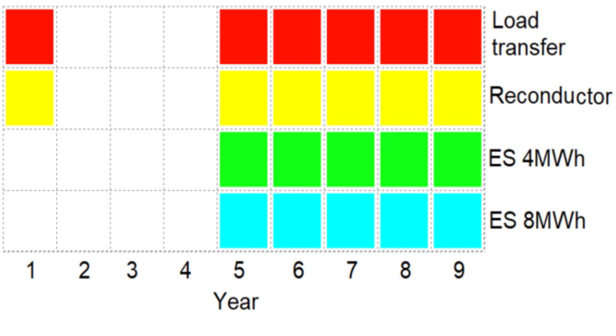
The other alternative that seemed to be successful on every year it was used was the reconductor. The cable selected for upgrading lines reporting thermal violations seems to be sufficient for relieving them at the year under analysis. The reconductoring module can also consider overload thresholds for updating lines that are close to their thermal limits before the overload takes place. The logic for using ES to relive thermal violations consists into placing the storage downstream at the end of the consecutive violations. The control settings for the storage device are current based setting the discharging target at the most overloaded line rating.

It is expected that the ES will serve the loads that are triggering the violation. The charging cycle takes place when the current at the most overloaded element, which normally is upstream the consecutive violations, is below a threshold set for such purpose. For this example, the charging cycle starts when the current at the monitored element is below the 20% of its ampacity rating. A similar principle guides the PV placing, however, in this case the control signal is given by the irradiance profile used. In this case, the daily demand peak and the irradiance profile are not coincident, making of PV a non-viable alternative for this study.

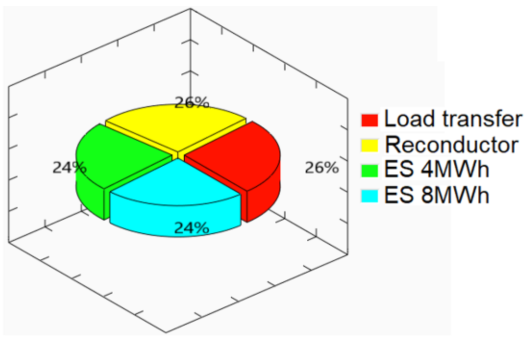
Even when ES doesn't seem to be as effective as load transfer and or reconductor on every year it is applied, when combined with other alternatives the study results reveal that its inclusion can contribute to successfully relieve the thermal violations. For example, in one branch of the DBT obtained, by only using reconductor in years 1, 5, 6, 8 and 9, the total length of line segments upgraded is 2.44 mi. In another branch in which reconductor is used in years 1 and 5 plus ES used in years 6, 7, 8 and 9, only 0.83 mi of line segments are upgraded and 20MWh of ES installed across the model. The combination of alternatives is also an opportunity form accomplishing regulatory goals for including NWAs.

For better explaining the alternatives utilization during the study consider Fig 4. FIG 4a shows the alternatives utilization per year, focusing on the years in which each alternative is used during the study. This graph reveals the years in which an alternative has at least one chance to relive a violation successfully. As can be seen in Fig 4a, load transfer and reconductor are the only alternatives capable of relieving the violations in year 1, which will keep with the circuit until year 5, where new violations appear. From year 5 and on, ES joins the set of alternatives capable of relieving the violations. On the other hand, Fig 4b displays the alternatives utilization rate across the DBT. This graph considers all the edges created across the DBT in which a corrective action took place, then, evaluates the number of times each alternative was used for relieving the violation effectively.

As can be seen in Fig 4b, load transfer, reconductor and the two sizes of ES selected for the study are very close in the utilization rate, suggesting that despite the case in year, some of the NWAs proposed (ES) have a good participation factor for reinforcing the circuit for the given planning horizon. The graphs presented in Fig 4 as well as the topology of the DBT, are tied to the circuit features and the set of alternatives selected for the study. At the end of the study, all the viable technical paths can be sorted by costing them, involving economic variables such as escalation, discounts, depreciation, life span, among others [8].



a)



b)

Fig 4. a) Alternatives utilization per year, b) alternatives utilization rate

Then, using the sorted list of paths, the utility can evaluate which path represents the best planning approach for not only get the best investment, but also cover regulatory requirements/goals.

CONCLUSIONS

This paper has presented a methodology for identifying potential alternative deployment scenarios considering the dynamic characteristics associated with NWA. The graph generated as the result of the study, allows to recreate time critical time instants dynamically for deriving new tangents/dimensions. The new dimensions found represent alternative timelines complementing an initial single investment plan. The alternative deployment is synthesized in a directed graph called DBT, containing the different dimensions or technical viable paths that recreate time critical time instants dynamically, deriving new tangents/dimensions representing alternative timelines complementing an initial single investment plan. The DBT also considers the boundaries set by the planning engineer, serving as the basis for detailed cost-benefit assessments and least-cost optimizations that will allow planners to identify the best investment plan according to the utility goals. The DBT representing all the possible technical solutions within the technical boundaries stablished by the planner, can serve as the basis for detailed cost-benefit assessments and least-cost optimizations.

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