Automated use of wired measures in grid planning for solving current and voltage band problems

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***Abstract*—This work deals with the use of cable exchange and parallel cabling as network expansion measures in the context of an automated grid planning for the elimination of current and voltage band problems in a distribution network. Inter alia, reference is made to a higher-level program, which is being developed in the EU project "CrossEnergy", and the procedures for remedying the limit value violations are presented.**

***Keywords*—grid planning, automation, cable exchange, parallel cabling, network expansion**

I. Introduction

The changes in the power grid, that accompany the energy revolution, pose new challenges for many network participants. In future, distribution system operators will also have to reckon with an increased number of renewable energy sources in their electricity grids and continue to guarantee safe operation. It is not uncommon that, with the connection of photovoltaic (PV) stations or wind turbines, limits are exceeded in terms of voltage or current. Changes in consumer behavior, demographic change or the integration of e-mobility can also cause network bottlenecks in distribution networks. In order to detect these difficulties and their consequences and to develop appropriate measures, it is necessary for the network operators to carry out detailed investigations. Automated calculations in grid planning can serve as a major support in planning a technically meaningful and at the same time economical network expansion [1].

II. Automation of Grid Planning Processes

When designing an automated grid planning program, it is crucial to develop concepts and algorithms that include generalized methods. This enables the handling of any network topologies and occurring problems. The calculated solutions should ideally represent a global optimum. It is possible to achieve this goal by means of probabilistic calculations, however, this is based on an enormous computing power as well as the determination of many partial results, which represent an inefficient problem solution. In order to reduce computing power and time, heuristics can be used to sort out irrelevant solution variants in advance. The problem with the mere integration of heuristics is often the limited application to the problem cases. Thus, there is the risk that an algorithm with a pure heuristic method can no longer filter out the best result from a separate solution pool or even finds a local optimum. Consequently, solution variants, that would be better, are not included and are not shown in the final results. To eliminate this inefficiency, heuristics are included in the proposed grid planning tool in order to keep the solution set as small as possible, but then supplemented by mathematical optimizations. Therefore, this method should ensure that the global optimum is taken into account in the final results. The search for the best results involves technical and economic aspects. Thus, it is also possible to search specifically for different optima, such as the solution with the lowest cost or greatest technical benefit.

III. Grid Planning Tool Included in the EU-Project CrossEnergy

The conception of the automated network planning arises in the course of the project CrossEnergy. This funded EU research project, created under the ETC goal, is concerned with the development of a decision support system (DSS) for the strategic development of electricity grids at the distribution grid level. The focus is on a common grid expansion planning in the Bavarian-Czech border region with regard to future scenarios for load and generation development. The main target groups are network operators and network subscribers, but the program is also intended to appeal to political decision-makers or other interest groups who would like to gain insight into the future development of electrical energy systems in a region [1].
The research project covers three topics with the Ostbayerische Technische Hochschule (OTH) Regensburg, the Technische Hochschule Deggendorf (THD) and the University of West Bohemia (UWB) in Pilsen: prognosis, grid planning and grid operation (see Fig. **1**). For this purpose, the THD provides energy data in the form of time series and installed power for current and future years as well as forecasts for load and generation development. In the course of a given scenario, OTH Regensburg implements the corresponding grid planning which is calculated fully automatically. Finally, the UWB compiles key figures and status assessments for the networks planned by OTH Regensburg, whereby a specially developed load-flow calculation program is utilized here. All three partners use a platform developed by UWB for communication and data exchange. The same data platform also has an interface to the user, who can, among other things, transmit his network and scenario data and then also receive the results of the DSS [1].

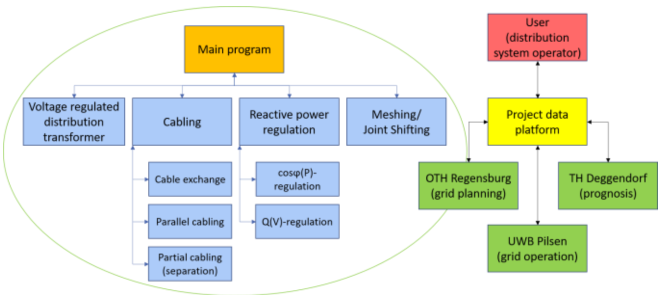

Fig. 1. System architecture of the DSS [1]

Fig. **1** shows an overview of the system architecture of the grid planning tool developed by OTH Regensburg. The main program manages the input and the output via the interface with the project database as well as the control of the individual network expansion measures. Depending on the selection of network expansion methods (e.g., cable exchange, Q(V)-regulation, etc.), load and generation development scenarios are calculated accordingly and a completed network model is returned to the platform. Thus, at the end the user has several options for a network expansion ready, which are accordingly occupied with technical and economic figures as a decision-making aid [1]. The measures can also provide several solution variants (see IV.A and IV.B). A distribution system operator then uses the final results to select, which expansion variant is best for his network. The focus of this work is on the wired measures.

IV. Automated Use of Cable-Bonded Grid Extensions

In this work, the cabling measures for network planning are categorized as follows: cable exchange, parallel cabling and partial cabling. The cable exchange represents the pure replacement of lines with a larger cross section (Fig. 2). The parallel cabling provides an additional line that is installed along a critical string (Fig. 3). The partial cabling is a modified version of the parallel cabling, which also installs a parallel cable, but adds a separation at the end node of the parallel cable (Fig. 4).

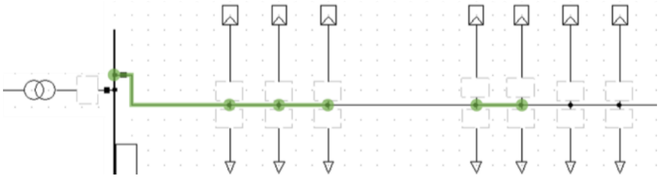

Fig. 2. Grid extension measure “cable exchange”

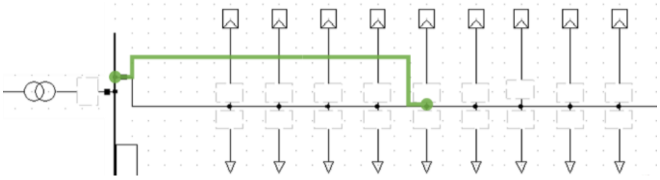

Fig. 3. Grid extension measure “parallel cabling”

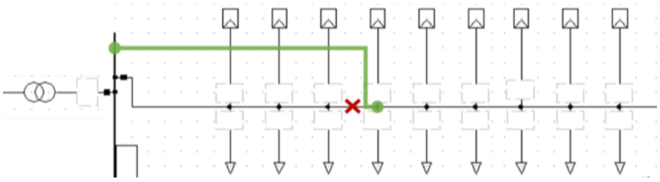

Fig. 4. Grid extension measure “partial cabling” (parallel cabling with separation)

All cable-specific measures can be used for solving current and voltage problems. In principle, when current and voltage limits are exceeded at the same time, current problems are always solved first, since this reduces or resolves in most cases the voltage problem, too. Solving the voltage problem first can also reduce or resolve the current problem, but experience shows that the chances are lower. In addition, the procedure "current problem before voltage problem" also covers a worst-case issue, which occurs with a voltage band, where most of load and generation power appear on different grid points in a string. This will be explained in more detail later (see section A). In order to present the heuristics and mathematical methods that have emerged in the development of an automated use of wired measures, the cable exchange and the parallel cabling will be discussed here deeper.

A. *Cable exchange*

After the routine made the load flow calculation of a distribution network, all faulty lines are sorted by error intensity. This means that the cable pieces and network nodes, which have the highest utilization or the largest deviation from the voltage limits, are first returned to a permissible network state (see Fig. 5).

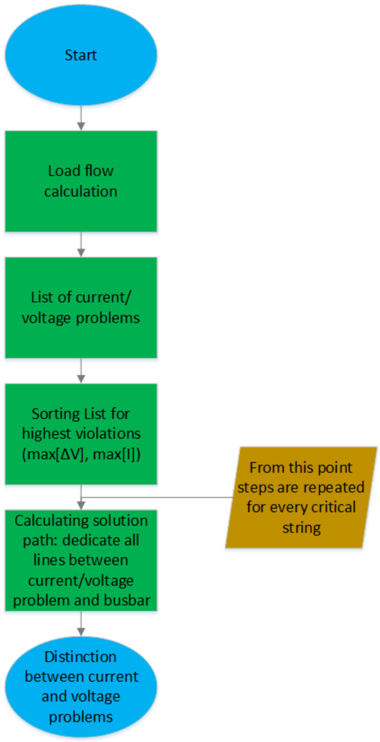

Fig. 5. Flow chart for identification of grid problems, sort of violated lines/nodes in error intensity and calculation of the solution path

To solve the current/voltage problems, the algorithm reads out additionally a solution path, which is extracted from the critical string. All lines from the affected path are then available for the routine to solve the problem by cable exchange. Fig. 6 shows how the solution path is detected.

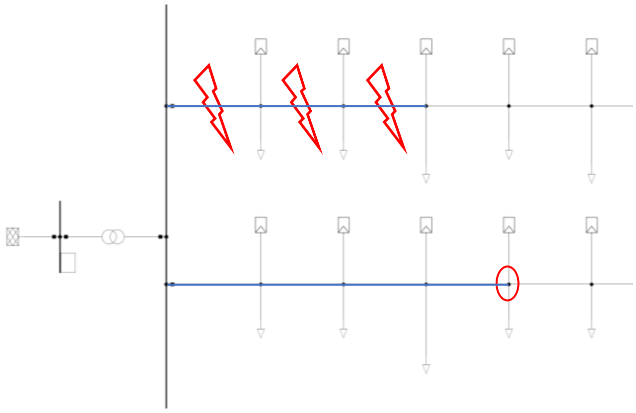

Fig. 6. Visualization of the solution path (upper string: current problem, lower string: voltage problem)

The sections with the red flashes represents lines, which are too heavily loaded. The point encircled in red depicts a network node with an impermissible voltage, and the lines marked in blue then reproduce the corresponding solution paths. The procedure is as follows: the algorithm is reading out all lines that are on the way to the nearest busbar beginning from the critical line or critical node.
From this point on, a distinction is made between the treatment of a current or voltage problem (see Fig. 7). Exceeding current limits are solved by replacing all lines that have too high utilization. In this work cable exchange always means the use of cables with a higher cross section. The exchange is done until the current problem is solved or no cable type with higher cross section is available, as on left flow chart of Fig. 7 depicted. The user can specify how many and which cable types are available for usage. If the user does not want to give input, then a default library will be used.

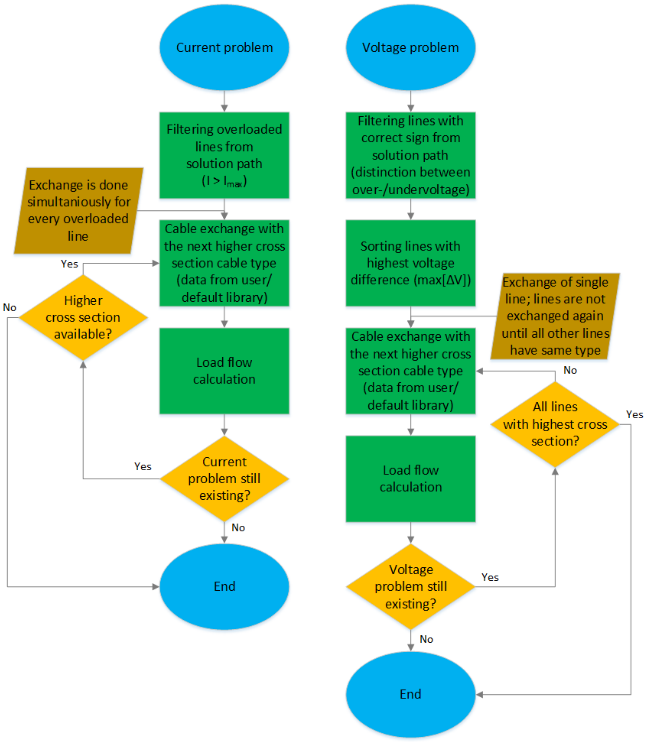

Fig. 7. Flow chart for current (left) and voltage (right) problems with cable exchange

The solution of voltage-related violations is more complicated to implement than current problems. Because here it is important to know the voltage band along the solution path and then to exchange appropriate lines. If a voltage problem is to be solved as technical effectively as possible, then firstly the lines must be replaced, which cause the highest voltage differences (Fig. 7, from second green shape on the right flow chart). Therefore, the exchange of the lines goes further from the highest occurring voltage difference to the line with the lowest, until the voltage problem is resolved or all lines from the solution path have the highest possible cross section. However, it would not be useful to hand this procedure over to the routine. As shown in Fig. 8, the cable exchange on the section with the highest voltage difference may even worsen the existing problem. In this example the cable exchange of the line, which causes the highest voltage difference (between nodes 2 and 3 in the blue curve), reduces the voltage increase at the beginning of the voltage band, but does not solve the low voltage problem in node 19 (orange curve), while the dashed lines (green) the voltage limits represent. Quite the contrary, the cable exchange aggravates the existing problem (form 0.885 p.u. to 0.865 p.u.). Therefore, only the lines that have a solution-relevant sign on the slope may be considered here, as at the beginning on the right flow chart in Fig. 7 illustrated. In the case of a low voltage problem, these are the line sections, where the voltage drops occur (in Fig. 8 lines between nodes 5 to 19).

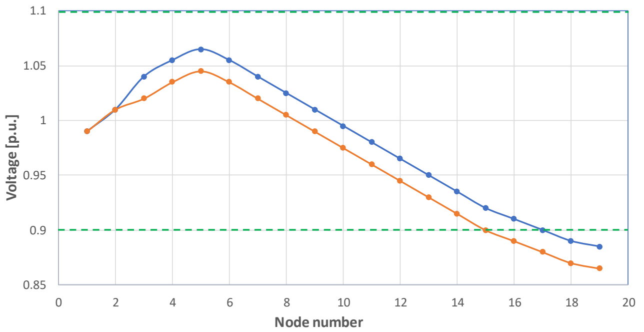

Fig. 8. Voltage band course before (blue) and after (orange) the cable exchange of the line with the highest voltage difference (between nodes 2 and 3); dashed lines (green) represent the voltage limits

The algorithm can further differentiate the results here. Because in the just described procedure, the lines, which cause the highest voltage differences with the correct sign, are replaced without considering whether the line sections are behind each other or if they are spread over the string. This can be expressed economically, for example, in authorization procedures and construction site costs. Furthermore, it would not be sufficient for the optimal result search, only to use the next higher cable cross section. So the algorithm should calculate the most economical solution by the use of the available cable types. These different optima can be limited by concrete specifications that the user makes. Thus, it is well conceivable, that the user gives, for example, the input for the replacing of several line sections that they must be behind each other.

B. *Parallel cabling*

As in the case of cable exchange, the critical lines and the solution paths are also determined here first and a distinction is made between solving current or voltage problems. The most effective solution to handle with a current problem in this routine is the pure parallel cabling of the overloaded lines. The line is not laid over each cable section parallel, but over the entire length of the problematic string part. The algorithm only deviates from this procedure if there is a branch between the overloaded lines (see Fig. 9).

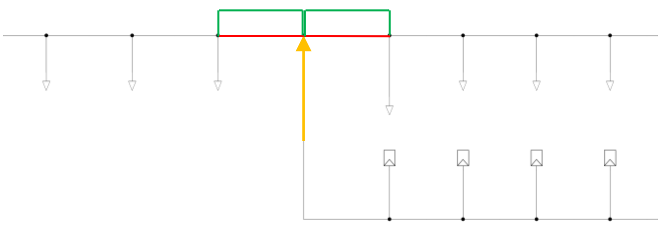

Fig. 9. Parallel cabling with crossing a branching point

Here is the parallel cable interrupted at the branch point (green marked lines) to make sure that the routine is, e.g. in the case of a high infeed from the lower string (orange arrow), able to solve the overload of the two red marked line sections.

The previously described concept of the shortest parallel cabling does not take account of cable distribution cabinets (CDC) that are present in the network. If they are now to be integrated into the solution process, a second implementation is obtained in addition to direct parallel cabling of overloaded lines. In this variant, the parallel cables are installed from busbar (BB) to CDC or from CDC to CDC. Technically, the resolution of the current problem is worse in this solution variant, but, inter alia, the installation of new stations can be prevented, which is economically better. However, this solution type requires an expansion of the considered equipment, which are used to solve the problem. So not only the CDC of the returned solution path are included, but all CDC of the string up to the next branch. Fig. 10 shows the described situation: the critical lines are marked with red flashes and the lines highlighted in blue corresponds to the solution path that the routine reads out. The orange encircled network nodes represent the relevant CDC, which are included in the solution finding. In order to calculate the solution here, all connection possibilities between the BB and the CDC as well as the CDC among each other are calculated and the shortest connection, which solve the current problems, is rated as the best result (see (1)). In the formula represents L_{PL} the solution of parallel cabling, which is from all connections between BB and CDC ($L_{BB,CDC}$) the shortest and coincident solving the current problem.

$$L_{PL} = \min(L_{BB,CDC}),\ \forall L: I < I_{max} \quad (1)$$

Here can be an important input from the user, how many connection ports are still available at the CDC, to take into account whether the distribution station has to be extended because of the parallel cables and how this would be expressed in the economic terms of the results. In the example shown in Fig. 10, it could be important to have this input to answer the question, if there should be a completely continuous cable from the busbar to the rear CDC, or if the parallel cable should be divided into two lines with connection to the first CDC.

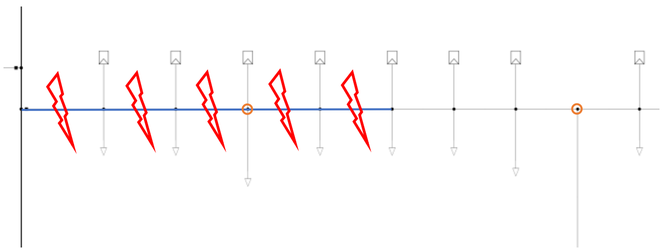

Fig. 10. Parallel cabling with consideration of CDC (orange encircled grid nodes) in the string (red flashes: current problems, blue marked lines: solution path)

The algorithm solves voltage problems in consideration of CDC with the analogous concept, which is used for current problems. In the variant of the shortest parallel cabling with regard to violated voltage limits, first the line section with the greatest sign-correct slope is chosen. If the voltage is exceeded, a parallel cable will only be laid in those parts of the string, which are increasing the voltage. From the line with the largest gradient (marked red in Fig. 11) the routine compares the adjacent lines (marked in orange) and considers this section for parallel cabling, which shows the greater slope. The algorithm will continue this procedure until either the voltage problem is resolved or no more sign-correct cable sections are left.

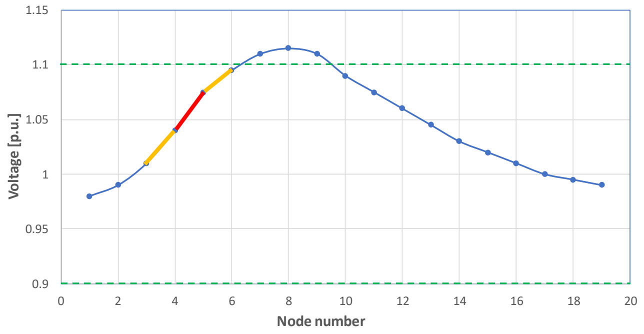

Fig. 11. Voltage band course with visualization of the approach of the measure "parallel cabling" with handling a high voltage problem; dashed lines (green) represent the voltage limits

V. Summary and Outlook

Automated grid planning is a suitable tool to show distribution system operators possibilities for future grid expansion. The combination of heuristics and mathematical optimization is more efficient than the pure probabilistic approach. The biggest challenge in the automation of network planning processes is the generalized procedure of the routine, so that any network condition, topology and problem in terms of voltage and current can be treated and the best possible solution is found. The EU project CrossEnergy is developing a grid planning program that implements inter alia the automated use of cable exchange and parallel cabling. The procedure for the detection of the problem areas and the strings, in which a corresponding measure is then implemented for the solution, is the same for both expansion technologies. Differences are mainly to be seen when dealing with current and voltage problems between cable exchange and parallel cabling. The treatment of overloaded lines is implemented in the cable exchange by replacing it with a cable type having a higher cross section. The resolution of voltage problems is realized by the systematic replacement of lines with the largest and sign-correct slope. In the parallel cabling measure, in case of a current problem, the cable is directly laid parallel on the overloaded line sections in order to obtain the best technical efficiency. In the case of a voltage problem, the line with the largest gradient is identified and again only those sections are considered, which have a sign-correct slope. From this line piece then the adjacent lines are compared with each other and the routine adds the line with the larger gradient to the pool for parallel cabling. The algorithm continues this procedure until the voltage problem is solved or no lines are left.

Automated network planning shows a great deal of potential in supporting network operators. The results are supported by technical and economic figures, so the user can decide, which expansion variant should be used for the future grid extension. The algorithm presented in this paper can be further developed in many ways. In order to get even better solutions in the case of wired measures, for example, land use can be included. With this additionally information, it is possible to give the line sections a weighting factor that indicates how expensive an exchange or a parallel installation is. This can serve as additional input for even more economic network development.

References

[1] H. Kraus, D. Gschoßmann and O. Brückl, “Automatisierung von Netzplanungsprozessen in der Verteilnetzebene – Q(U)- und cosφ(P)-Blindleistungsregelung dezentraler Anlagen als spannungshaltende Netzausbaumaßnahmen“, transcript of the conference *Zukünftige Stromnetze für Erneuerbare Energien*, p. 407-420, Berlin, January 2019.