A Novel Hybrid Network Architecture to Increase DG Insertion in Electrical Distribution Systems

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***Abstract*—Distribution networks will experience a deep mutation concerning their planning and operation rules due to the expected increase of distributed generation (DG) interconnection to the grid. Indeed, the opening of the electricity market or the growing global concern for environmental issues will lead to a massive development of DGs. Yet, a too large amount of DGs could raise technical problems on distribution networks which have not been planned to operate with bi-directional power flow. The existing solutions to solve marginal DG connections could be no longer relevant. The distribution network definitely has to evolve towards a smarter and more flexible network. Two possible ways to reach this goal are through new architectures and developing intelligent systems. This paper focuses on new architectures and operating modes. The traditional radial distribution network could accept more DGs by introducing appropriately specific loops. A new hybrid structure enabling the coexistence of the radial and meshed operation is proposed. It is equipped with autonomous circuit-breakers and automated switches that improve its reliability. A heuristic algorithm is also proposed to build this new architecture while ensuring the equality of consumers with respect to the continuity of service and while minimizing the global cost.**

***Index Terms*—Distributed generation, distribution network, optimization, planning, Traveling Salesman Problem.**

I. Introduction

THE distributed generators (DGs) are small production units based either on renewable energy sources (such as wind and solar photovoltaic) or conventional energy (such as small gas engines or diesel generators) that are connected to the distribution network. Their installed capacity reaches 10 MW in the USA and 12 MW in France [1], [2].

In the near future, the growing concern for environmental issues as well as for the security of supply is expected to lead to the development of local renewable DGs. These power sources will be connected to the distribution network which had been designed to see only unidirectional power flows, from upstream to load. Nevertheless, concerning consumption and production conditions, DGs have been reported to have considerable impacts on the distribution network [3]. First, DGs can modify the electrical values such as voltages, currents, and power flow. The voltage profile in the distribution network depends on both the injected active and reactive power by DGs and the loads. It is presently well known that the interconnection of DGs can lead to the violation of voltage limits, to the dysfunction, and even the deterioration of the network components. In addition, power flows that were unidirectional, coming from the transmission network to the end users, can be modified by the injected power of DGs. Consequently, in some circumstances, the maximum allowed current of a conductor can be exceeded. If the production of DGs is greater than the global consumption, the distribution network could export power. The short-circuit currents can be modified and lead to undesired behaviors of the protection scheme (e.g., protective relay blindness or inopportune trips). Furthermore, DGs supply the short-circuit current that may exceed the operating limits of the network elements [4]. The quality of the voltage can also be reduced [3].

In many countries, in order to face these problems, the reinforcement of the network or the dedicated feeders is used. The first solution consists in detecting the part of the network where constraints are violated. In case of current (or voltage) violation, the gauge mutation of conductors can annihilate the problem. The second solution consists in connecting the DG with a dedicated feeder directly to the HV/MV substation. By doing so, the power flow becomes unidirectional in normal operation mode.

Although connecting marginal quantities of DGs in the distribution network is currently well managed using "business as usual" techniques (reinforcement and dedicated feeder), the systematic use of dedicated feeders could become a very expensive solution to manage while considering a significant development of DGs.

New solutions must, thus, be found to assist the introduction of a large amount of DG in the distribution network. Some studies proposed to change the operation mode of the distribution network, inspired by the transmission network, which uses a meshed operation. This solution has been considered as inapplicable for many years due to the parallel operation of transmission network and distribution network. Such a solution could prove to be dangerous without implementing an appropriate protection scheme since loops currents are created. Recent studies have proposed to use current limiters or D-FACTS [5] that limit loop and short-circuit currents [6]. Further studies report that meshing could be a competitive way to increase the connection of DGs in the distribution network [7]–[13].

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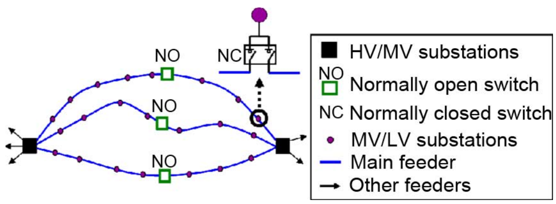

Fig. 1. Secured feeder.

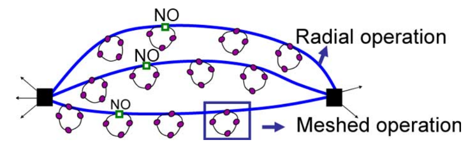

Fig. 2. Hybrid structure.

This paper proposes a new architecture called hybrid structure which can increase DG connection to the network. This architecture is an evolution of an existing architecture which is radially operated which introduces partially meshed sub-feeders. Beginning from the location of HV/MV and MV/LV substations, an algorithm that builds the hybrid structure ensuring the equality of consumers regarding the energy supplied while minimizing the total length of conductors is proposed. This algorithm has been applied on an existing urban network and the capacity of the hybrid structure to accommodate DGs is highlighted.

II. New Architecture to Increase DGs Insertion: The Hybrid Structure

A. Current French Network Architecture

The main challenge of distribution long-term planning was to find the best architecture ensuring a good service quality while minimizing the global cost. This challenge has lead to the secured feeder structure [14] which is the most encountered architecture in France and many countries, as depicted in Fig. 1. Each consumer is supplied by several main feeders that link two HV/MV substations. The radial operation is ensured by using normally open switches in every main feeder. A main feeder consists of two radial feeders usually limited to 6 MW.

The desired service quality leads to a given number of main feeders and the choice of the consumers connected to them. The usual service quality notions include:

- System Average Interruption Duration Index (SAIDI) expressed in minutes per year;
- System Average Interruption Frequency Index (SAIFI) expressed per year;
- expected energy not supplied (EENS) expressed in kWh per year;
- equality of the consumers regarding the EENS. This index is ensured by creating areas with equivalent product PL.

For a given area, the product PL is the product of the total power demand (in MVA) and the total length of conductors connecting consumers to HV/MV substations (in km). If this index is balanced, areas having a small consumption will be supplied with longer conductors than areas having a higher consumption. The probability that a fault occurs on the network is proportional to the length of conductors. Thus, the statistical power cut during a fault is minimized if the PL is balanced. The service quality is improved. Consequently, the EENS of two areas with the same PL will be statistically the same. In the secured feeder, each main feeder has the same product PL.

In areas where the expected service quality is high, the secured feeder can evolve into two main structures: the grid and the loop [14], which are also radially operated. The redundant paths increase the service quality but the operation of such structures can be very complex, and can also be very expensive.

In the future, the parameter "distributed generation" should be integrated in the objectives of the long-term planning. Hybridization between the secured feeder and the permanent loops could be a novel way to increase DG connection, ensuring the service quality and minimizing the global cost.

B. Hybrid Architecture

The hybrid structure is illustrated on Fig. 2. As in the secured feeder, consumers are supplied by radially operated main feeders using normally open switches. But the main feeders are not directly connected to the consumers. They are connected with other consumers or producers on secondary circuit (sub-feeders) which are looped.

In case of a fault on the main feeder and after the trip of a circuit breaker within the HV/MV substation, the network is rearranged by changing the state of the normally opened and closed switches. In case of a fault inside a loop, a "distributed" circuit-breaker disconnects only the loop so that the main feeder and the other loops are not affected by the fault. Each MV/LV substations in the loop can be equipped with automated switches that can quickly locate and isolate the fault. The loop can be, then, reconnected to the main feeder in order to reenergize the healthy parts [14].

The procedure to reenergize consumers in case of a fault is faster than that of the secured feeder. Therefore, the SAIDI and the EENS decrease. The partially meshed operation will increase DG connection. Finally, supply and consumption balance can be ensured by defining PL equivalent areas. As in the secured feeder, each main feeder and each main feeder have equivalent PL products and each loop has an equivalent PL.

C. Definition of the Evaluation Indexes

The building of the hybrid structure consists in linking consumers and producers respecting the balancing of PL product. This structure is expected to increase the DG connection, to ensure the quality of service (SAIDI and SAIFI) and to be competitive. In this subsection, the different indexes (balancing the PL product index, global cost, SAIDI, SAIFI, and maximal DG insertion rate) are mathematically expressed.

1) Balancing the PL Product: The PL balance is expressed by using the standard deviation E of the PL product regarding the mean of the PL product. Formula (1) gives the expression of criterion E:

$$E = \frac{\sqrt{\frac{\sum_{i=1}^{n}(PL(i)-\overline{PL})^2}{n}}}{\overline{PL}} \times 100 \quad (1)$$