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Reconfigurable DC Links for Restructuring Existing Medium Voltage AC Distribution Grids

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paper revolve around, is to present a viable way of gradual transition from AC to hybrid AC–DC to finally a universal DC system.

Keywords::

AC DC distribution grids reconfiguration flexibility restructure

1. Introduction

Increasing integration of dispersed renewable energy sources in existing electricity supply systems has enabled bidirectional power flows in the AC distribution networks. New energy consumers like electric vehicles, all electric houses, and heat pumps have changed the localized energy consumption patterns and increased the expected demand from grid infrastructure several folds [1, 2]. Infrastructural complexity and investment costs are required for maintaining sufficient and optimized power flows to cope with localized demand deficits and quality of supply at acceptable voltage deviations. The distribution network operators should have adequate flexibility and control on the grid operation. Reconfigurable DC links incorporated in the existing AC distribution grids can provide solutions to the challenges highlighted in the subsequent section. ... s [3] like lower los ... idirectional power c ... nd storage, while off ... cies such as converte ... ink converte ... grid operatio ... are listed and ... ghted.

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The subsequent section elaborates on these challenges and opportunities. Then, the new concepts developed in this paper are presented and their potential is identified by reviewing the existing conventional practices. Finally, the limitations of the DC link technology and the means of mitigating them are discussed.

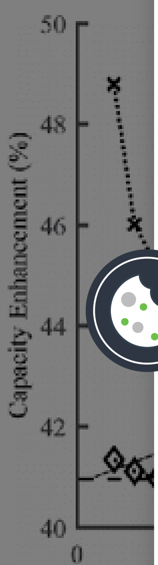
2. Challenges and Opportunities

2.1. Increase in Power Demand

A shift toward electric energy from traditional fossil fuel use in vehicles and heat pumps may trigger the need to enhance the capacity of existing distribution grids [4].

- Electric vehicles (EVs) have high charging power demand. User behaviour of charging the EVs at certain scheduled time of the day could create local overload on the grid even though the installed capacity is enough for average loading conditions [25].
- Interest in adopting all-electric houses has increased the reliance on electrical energy [26]. Some DNOs expect a significant hike in demand on their grid infrastructure if electrical heat pumps are used instead of conventionally used gas pipes.

FIGURE ... -phase AC link oper...



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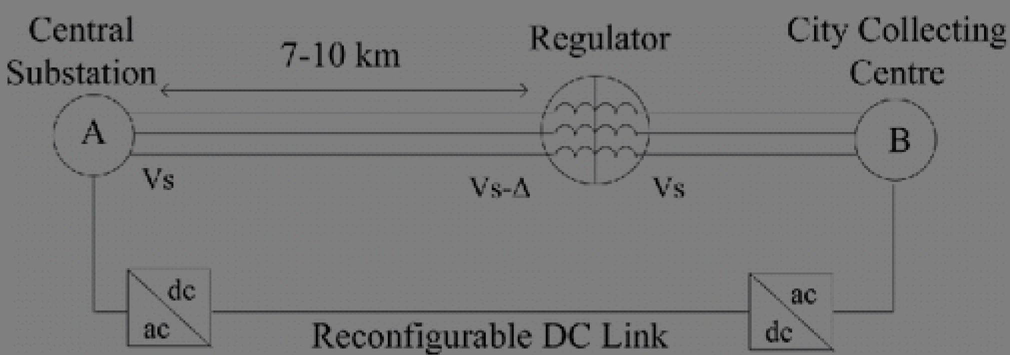
At a medium-voltage level of 10–66 kV, the transmission lines which bring the bulk power into the city collecting center from the central substation as shown in Figure 1 are at maximum loading conditions. The downline changes in loading pattern seldom take into account the consequences on this critical link. The reactionary responsibility of infrastructure overhauling falls on the DNOs. In case of overhead lines, modification to dc transmission can have considerable increase in power transmission capacity [27] Similarly, with use of dc links, the power transfer capacity of existing underground cable infrastructure can be significantly enhanced [4] as shown in Figure 2. A detailed quantification of capacity enhancement under different scenarios is offered in [28].

FIGURE 2. Reconfigurable DC links for bulk power transmission into the city collection center.



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require an intermediate AC–DC–AC conversion stage. A DC interconnection can lead to the reduction in a conversion stage, thereby improving the efficiency. The creation of flexible DC nano-grids controlled independently in a distributed way and interconnected via a DC grid in an open energy system may lead to de-congestion and solve problems of intermittent nature of generation locally [7, 10].

3.1. Meshing and Redundancies

The ability to revert to AC when the DC link operation fails during contingency is an important requirement, particularly at critical locations of bulk power transfer. Therefore, the architecture proposed is hardware-reconfigurable with the possibility of operating in both AC and DC.

An advantage of interconnecting different grid locations, thereby creating active closed loop grid architectures, is anticipated to fundamentally change how the future power grids will be designed and operated. The concepts such as network and fault reconfiguration of existing AC networks using optimally placed DC links are a pioneering focus of this paper.

3.2. Operational Flexibility

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- Control reconfigurability for greater flexibility and grid-supporting ancillary services.
- Network reconfigurability for loss minimization and feeder load redistribution using DC links.
- Fault reconfigurability for achieving higher availability.

This section explores the potential of these ideas further and supports their viability by highlighting the current and anticipated limitations of conventional AC utility grid architecture, control, and practices.

4.1. Hardware Reconfigurability

Figure 3 depicts one of the hardware system reconfigurations that can work as a bipolar DC link as well as revert to a three-phase AC operation during converter faults by a modular repair scheme. In this scheme, the three core cables operate as a bipolar DC link under normal operational conditions. Two of the cables can be fully loaded, while one is either redundant or acts as a return path as shown in Figure 3(a). During converter faults, which are the least reliable part of the system, the circuit breakers on the AC side open and the faulted components can be modularly removed as shown in Figure 3(b). The system can revert back to a three-phase three-line AC operation as shown i [illegible] s at both sides.

FIGURE [illegible] rground cables.

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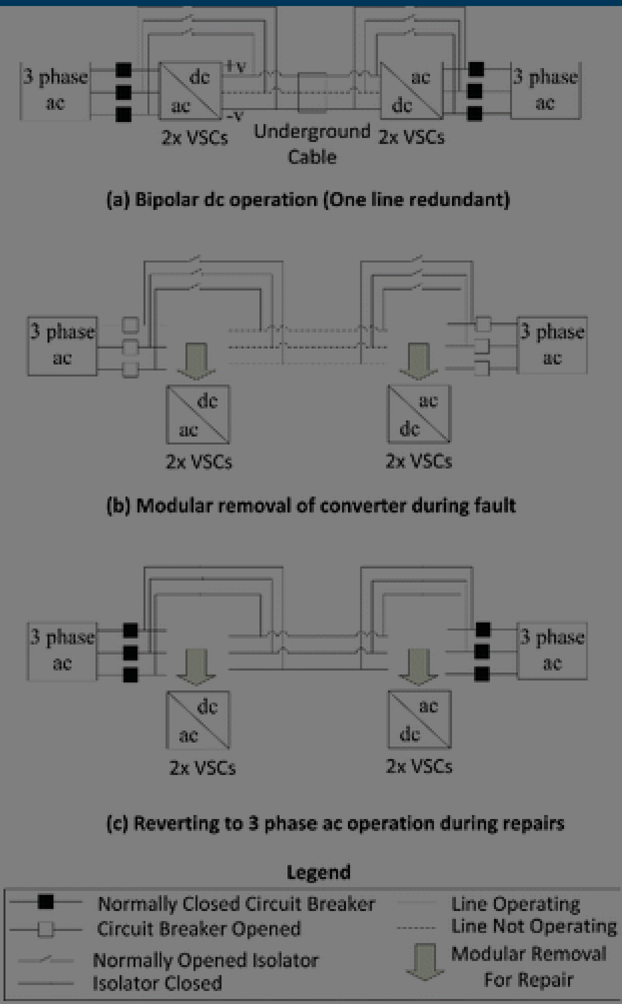

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In this way, we not only achieve a flexible and modular AC–DC operation by reusing the same underground cable infrastructure, but also save costs by common use of the circuit b … ed only for AC conn … solators are not oper … only connect … und AC cable to opera …

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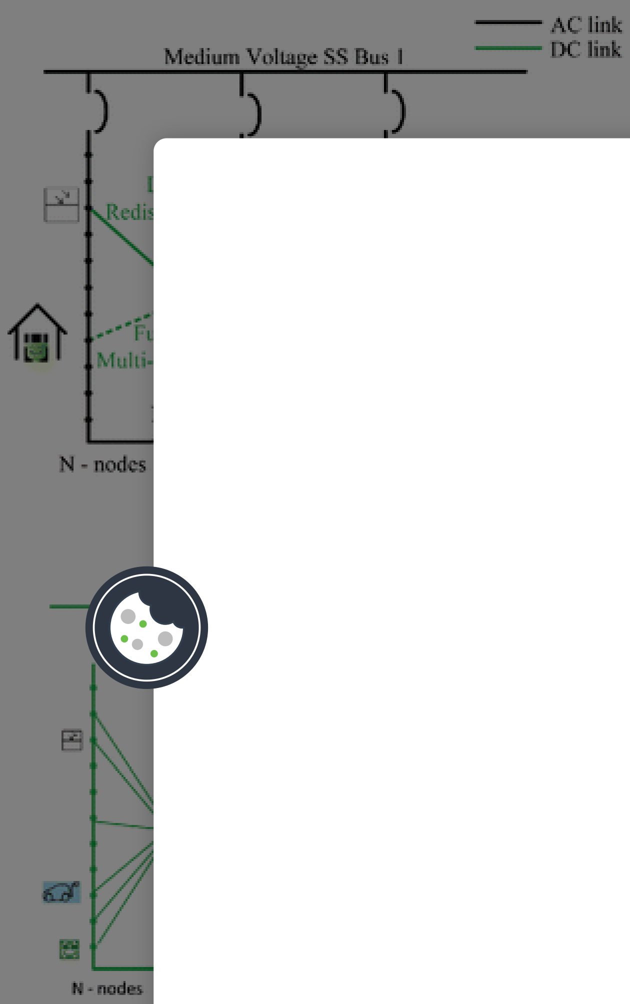
grids which are then operated in a radial mode and restructured using switching operations through efficient optimization techniques [14]. While such techniques of branch exchanges for the network reconfiguration have been explored extensively in the literature, the radial constraint is respected in all such studies [11–16].

Interestingly, it was noted as an afterthought in [16] that if a network configuration with a limited number of loops could be allowed, substantial reduction of resistive line losses over those of the optimum radial configuration may also be achieved. Considering that at the distribution level, a looped operation was unfavorable for AC, this was never explored further.

Considering that the point-to-point DC links can asynchronously interconnect two AC grid locations, it can be easily appreciated that the benefits of “radial” AC operation and network reconfiguration for loss minimization, load balancing, service restoration, and reactive power support using a flexible DC link backbone can be combined [24]. The An optimal placement of dc links in existing ac distribution networks can be beneficial, as illustrated in Figure 4.

FIGURE 4. Network restructuring using reconfigurable DC links.



Trade-offs in terms of cost of front and back convertors for DC links and their operating losses are added constraints, while new benefits such as rapid response, better control, efficient cable operation, enhancement in power transfer capability, and flexibility with ancillary services like harmonic elimination, power redirection, and voltage support should be incorporated in future problem formulations in this field.

The most interesting potential of this concept is the scalability of a multi-terminal DC skeleton within the existing AC grid, integrating distributed generation resources and energy-intensive consumers to achieve a “Grid within a grid,” therefore, paving way for the vision of realistically transitioning toward a universal DC distribution in a systematic way, as illustrated in Figure 4.

4.3. Fault Reconfigurability

The hybrid AC/DC medium-voltage system has great advantages over conventional AC distribution systems. In the conventional AC system, the tie switches are usually used to achieve service restoration once the fault occurs. This existing fault mitigation strategy has some disadvantages. First, after the fault is isolated, the downstream loads would be interrupted before they are reenergized by another feeder. Second, the new network topology caused by the closing of tie switch will cause high system losses and poor voltage profiles along the feeder since the closing of tie switch makes the main fee... to-point reconfig...

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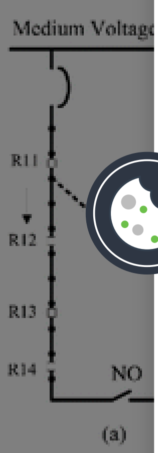

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In case (b), when fault F1 occurs between R12 and R13, that section is isolated and the nodes from R13 and end point are fed by closing the NO tie-line. The DC link converters generally have a fault ride through capability and can remain in operation. In this case, there is not much difference as compared to the system without the DC link, apart from the fact that the performance can be better due to inherent tolerance to over-currents and the capability to support the node voltage.

In case (c), when fault F2 occurs near the main bus, the DC link can provide supply to a downstream node and it is not necessary to switch in the tie-line. Apart from reducing the number of switching operations, this scenario also results in a better voltage profile and lower losses. It also does not result in a change in the current direction, which is an issue with an over-current relay coordination discussed in [15].

Similarly, in case (d), fault F3 can be isolated without interrupting the supply to other loads and avoiding the need to operate the tie-line. Therefore, it can be concluded that any fault between the main bus and the DC link end will reduce the tie-line operation and the losses, while improving the overall voltage profile. For faults between the DC link end and the tie-line, the fault ride through can guarantee a similar better performance than the original system.

It is also important to consider the constraints' relay coordination (R11–R14 and R21–R24) which is applied to the network reconfigurability. In the conventional radial system reconfig ... idance of some br ... DC link placeme ... es.

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other as shown in Figure 6. In case there is excess generation due to distributed sources in phase a1 in one part of the grid and local power deficit due to high demand in phase c2 in another part, the power can be redirected easily, efficiently, and rapidly by reconfiguring the converters without synchronization issues. This redirection may be beneficial in low-voltage microgrids with local pockets of power surplus and deficits. An adequate control algorithm for the DC links can offer flexibility in the operation of the distribution grid.

- If a bipolar configuration is employed, the system can be reconfigured to operate in a monopolar mode for limited time [1] with 50% capacity during single-line faults.
- Flexible operation of link converters as STATCOM for reactive power injection and harmonic elimination when the link is operating under AC conditions.

5. Limitations in Employing Reconfigurable DC Link Technology

Given the less mature market for DC technologies, particularly in terms of DC breakers [17] and minimal penetration of DC transmission in MV/LV distribution grids, point-to-point connections as a flexible backbone to the AC network are preferable as the starting point. To have more meshed interconnection and renewable energy integration toward t ... ed:

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reconfigurability of the DC link, as suggested in this paper, will improve reliability and ensure uninterrupted operations during contingencies.

Protection

A reliable and coordinated protection strategy is perhaps the greatest hindrance toward a truly interconnected meshed DC network [6]. DC links can prevent AC faults from affecting other parts of the AC grid. However, the use of switches, which are prone to failure, and the nature of the DC current itself make protection one of the biggest challenges in DC links. So far, DC point-to-point connections have only been protected via the use of AC breakers. This is also the reason why we limit ourselves in highlighting the potential of point-to-point reconfigurable DC links. In the case of Line-Commutated current-sourced convertors technology, the thyristor valves can block their operation and thus prevent the AC side from feeding the DC fault. However, this is not possible in the case of voltage-sourced convertors. As soon as a fault occurs, the control is blocked and the converter operates as a diode bridge continuously feeding the fault until a means of isolation is activated. Unless a DC grid is in place, no fast DC fault isolation is required, as the faulty DC line can no longer assist the normal power flow and it will need to be shut down for maintenance [18].

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6. Conclusion

Installing reconfigurable DC links in existing AC distribution networks can offer modularity and redundancy, flexibility of operation, and optimized power flow with loss minimization, as well as better availability and performance during faults. The novel ideas presented in this paper open an entirely new research direction in designing future hybrid power systems with a more involved AC and DC integration.

Hardware reconfigurability to achieve a modular AC–DC link operation not only allows grid operators to test the operational benefits of DC power transfer, but also gives them the option to revert to AC operation during contingencies like link converter fault, which are the least reliable part of the proposed system. Common use of circuit breakers and cables during AC and DC operations offers savings in infrastructure costs incurred.

Network reconfigurability with DC link breaks a limiting radial constraint that the AC distribution system imposed in the load balancing and loss minimization problems. The proposed concept is scalable to multi-terminal DC systems. An efficient interconnection of DC-distributed generation sources like PV and energy-intensive consumers like EVs makes it possible to integrate a DC “nano-grid within the grid.”

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Additional information

Funding

TKI Switch2SmartGrids(FLINK)

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