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Research Paper

Congestion Management Strategies in Active Distribution Networks

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Abstract**—**Microgrids play a vital role in future distribution networks. In this regard, dispatching the generation & unit commitment strategies are not directly applicable to this kind of generation/demand structure. Transmission systems as part of the conventional power systems have mature strategies for dispatching and especially remedies to cope with congestions in critical paths. In this paper, it is assumed that the main distribution system is composed of different individual microgrids as single identities connected to the distribution grid. Congestion management is of primary concern in the tie lines connecting the microgrids to the utility grid or between the microgrids. Back-to-back Voltage Source Converters (VSCs) as an interfacing facility is used to cope with the congestion in the interconnecting lines. Thyristor Controlled Series Capacitor (TCSC) is also proposed as the controlling device to manage the congestion. Other strategies like using a central controller with communication links to the microsources in order to dispatch remedial actions is also proposed; and ultimately optimal switching of the existing paths are used to mitigate the congestion.

Keywords**—**congestion management; formatting; Back-to-back Voltage Source Converters (VSCs); Thyristor Controlled Series Capacitor (TCSC); microgrid

I. INTRODUCTION

Microgrid is a new concept interpreting as systematically grouping a cluster of loads and paralleled Distributed Generation (DG) systems, powered by microsources such as fuel cells, photovoltaic cells, and microturbines in a common local area. Being a larger entity, a microgrid is anticipated to have a larger power capacity and more control flexibilities to fulfill system reliability and power-quality requirements, in addition to all inherited advantages of a single DG system. The formed microgrid can operate in two distinct modes; i.e., utility-grid (macrogrid) connected mode and autonomous (islanding) mode. In autonomous mode the DGs could serve the connected loads in full or partially by shedding the remaining ones [1]-[12].

Congestion management is referred to the prevention of the thermal overloading of the transformers and cables. Dispatching the generation of the available DGs and importing/exporting power from/to the macrogrid is key point that influences the operation of the microgrid and increases the complexity of the microgrid's operation. A microgrid operates in two modes; if the amount of generated power within the microgrid is less than the consumer's load, then the main grid will compensate the shortage of power supply. If the power generation is more than the consumer's load, then the surplus of the generated power will be injected to the main grid. The same scenario would apply to adjacent microgrids, i.e., adjacent microgrids can cooperate in order to balance the generation and consumption. Hence, microgrids can help each other and improve their performance during islanding condition or even connected to the utility grid by using proper control strategy. Regarding this important point, the direct connection of two adjacent microgrids with central controller to improve their dynamic performance is presented in [7] and significant improvements are achieved in comparison to the individual operation.

In this paper the congestion management of the tie line connecting the microgrid to the upstream grid or between the microgrids is investigated. Different strategies are proposed and analyzed to cope with this problem. The pros and cons of different proposed strategies are presented.

II. CONGESTION MANAGEMENT STRATEGIES

Fig. 1 shows a sample network consisting of two microgrids connected to each other by a line and also each of them are individually connected to the upstream utility-grid. As can be seen from this figure, there is a possibility of power exchange between the microgrids and between each microgrid with the related upstream macrogrid. The issue is how much power (active and also reactive power) is allowed to be transferred by the interconnecting lines such as no congestion occurs. It is worth noting that the power exchange is determined by the power flow characteristics of the network, so there is no obvious control on the flow of any line, unless some special equipment are anticipated [16].

Another point that needs attention is that the thermal overloading as the basis of congestion management is related to the line ampacity, i.e., the resultant active and reactive powers determines the permissible current of the line. So, it is necessary to consider both of them in the study, meanwhile it is recommended to supply the required reactive power within the microgrids as much as possible[13-15].

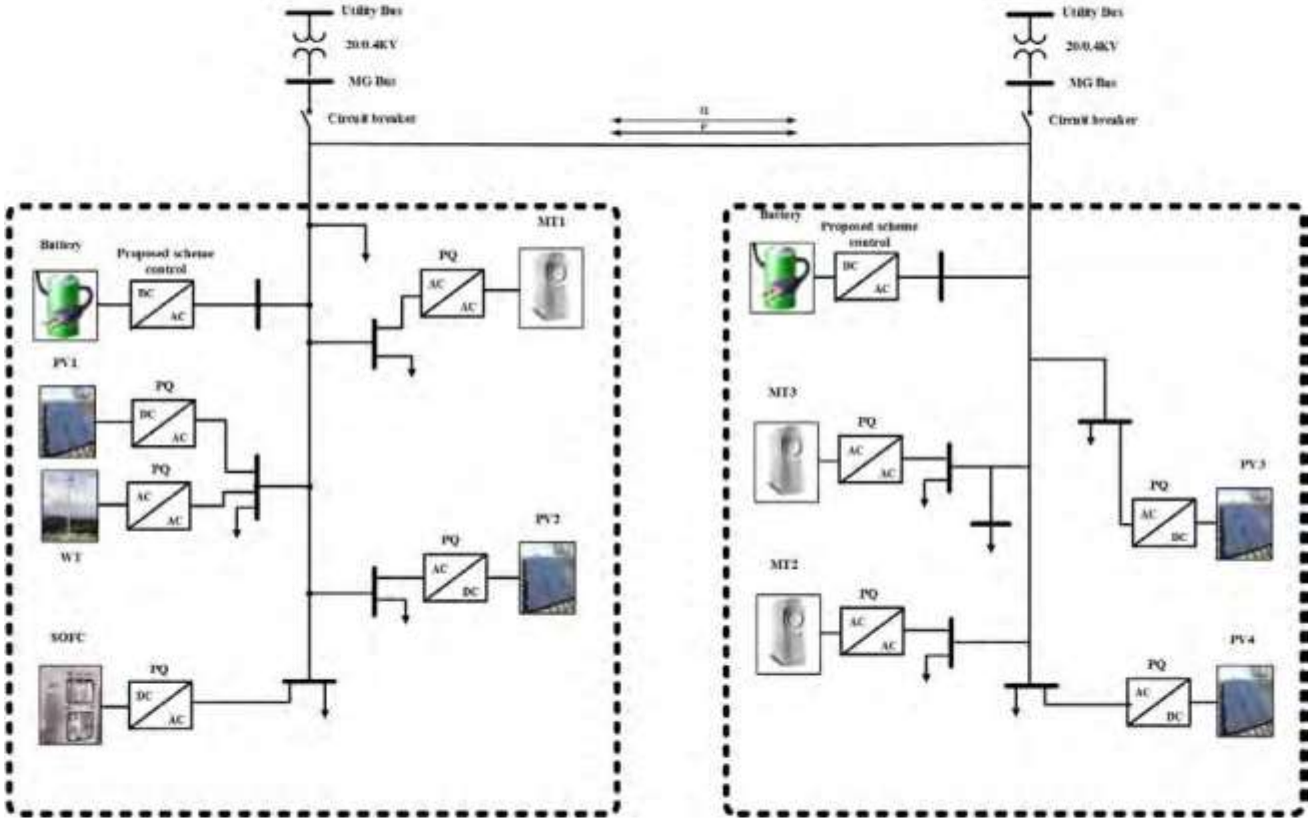

Fig. 1: Sample power system

III. STRATEGY I: USING BTB VSCS

In this strategy, it is assumed that the microgrids are connected to each other and also the upstream network by back-to-back Voltage-Sources Converters (VSCs). As these VSCs have enough flexibility to be controlled in such a way that does let more than a specified amount of power to be exchanged, so the issue is mitigated. If the microgrid needs more supply, the local controllers force the DGs within the microgrid to participate more in providing the demand. Hence congestion is avoided by an easy-to-implement solution. The control system of the back-to-back VSC could be adaptively tuned based on the weather condition, economic situation and all the other technical and non-technical constraint [17,18].

A general diagram of BTB VSCs is illustrated in Fig. 2, where E_k and V_k are the voltages of the microgrid and the BTB VSCs' output buses, respectively.

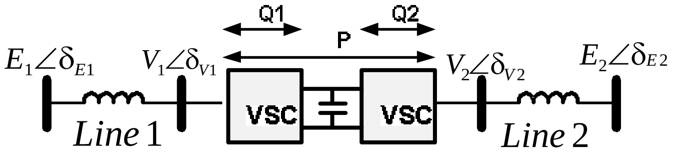

Fig. 2: General diagram of BTB VSCs

The considered BTB VSCs should be able to transfer the specified amount of active and reactive powers between E1 and E2 buses. To control the transferred power, equations of “dq” axes are used. More explanations are as below:

It should be noted that in the following equations if *k* is equal to *1* or ***2***, the voltages of each side of the BTB VSC will be obtained. Transferring three phase voltages and currents of both sides of BTB VSC to d-q reference frames which rotates with angular velocity synchronized with bus “E_k”, voltages in d-q axis can be expressed as equation (2):

$$E_{q_k} = 0 \tag{1}$$

$$E_{d_k} = E_k \tag{2}$$

Voltage equations of V_k bus in d-q axis is obtained from equation (3):

$$\begin{aligned} V_{d_k} &= E_{d_k} + L_k \frac{di_{d_k}}{dt} - \omega L i_{q_k} \\ V_{q_k} &= E_{q_k} + L_k \frac{di_{q_k}}{dt} + \omega L i_{d_k} \end{aligned} \tag{3}$$

In (3), the currents of d-q axis have mutual coupling. They can be considered as voltage disturbances and can be expressed separately as in equation (4):

$$V'_{d_k} = L_k \frac{di_{d_k}}{dt}$$

$$V'_{q_k} = L_k \frac{di_{q_k}}{dt} \qquad (4)$$

According to (4), variations in i_q and i_d currents contribute to the voltage variations of same axis, respectively via first order differential equations. Provided a proportional integral controller is implemented, it can produce the references for currents and voltages. Hence:

$$V^*_{d_k} = E_{d_k} + \left(K_{dp} + \frac{K_{di}}{s}\right)(i^*_{d_k} - i_{d_k}) - \omega L i_{q_k}$$

$$V^*_{q_k} = E_{q_k} + \left(K_{qp} + \frac{K_{qi}}{s}\right)(i^*_{q_k} - i_{q_k}) + \omega L i_{d_k} \qquad (5)$$

To control active and reactive powers with negligence of inverter losses, active and reactive power produced by the inverter can be yielded using (6):

$$P_k = \frac{3}{2}(E_{d_k} i_{d_k} + E_{d_k} i_{d_k}) = \frac{3}{2} E_{d_k} i_{d_k}$$

$$Q_k = \frac{3}{2}(E_{q_k} i_{d_k} - E_{d_k} i_{q_k}) = -\frac{3}{2} E_{d_k} i_{q_k} \qquad (6)$$

According to this strategy the transferred active and reactive powers between the microgrid and the upstream utility grid or between the adjacent microgrids are managed properly by using an appropriate control strategy.

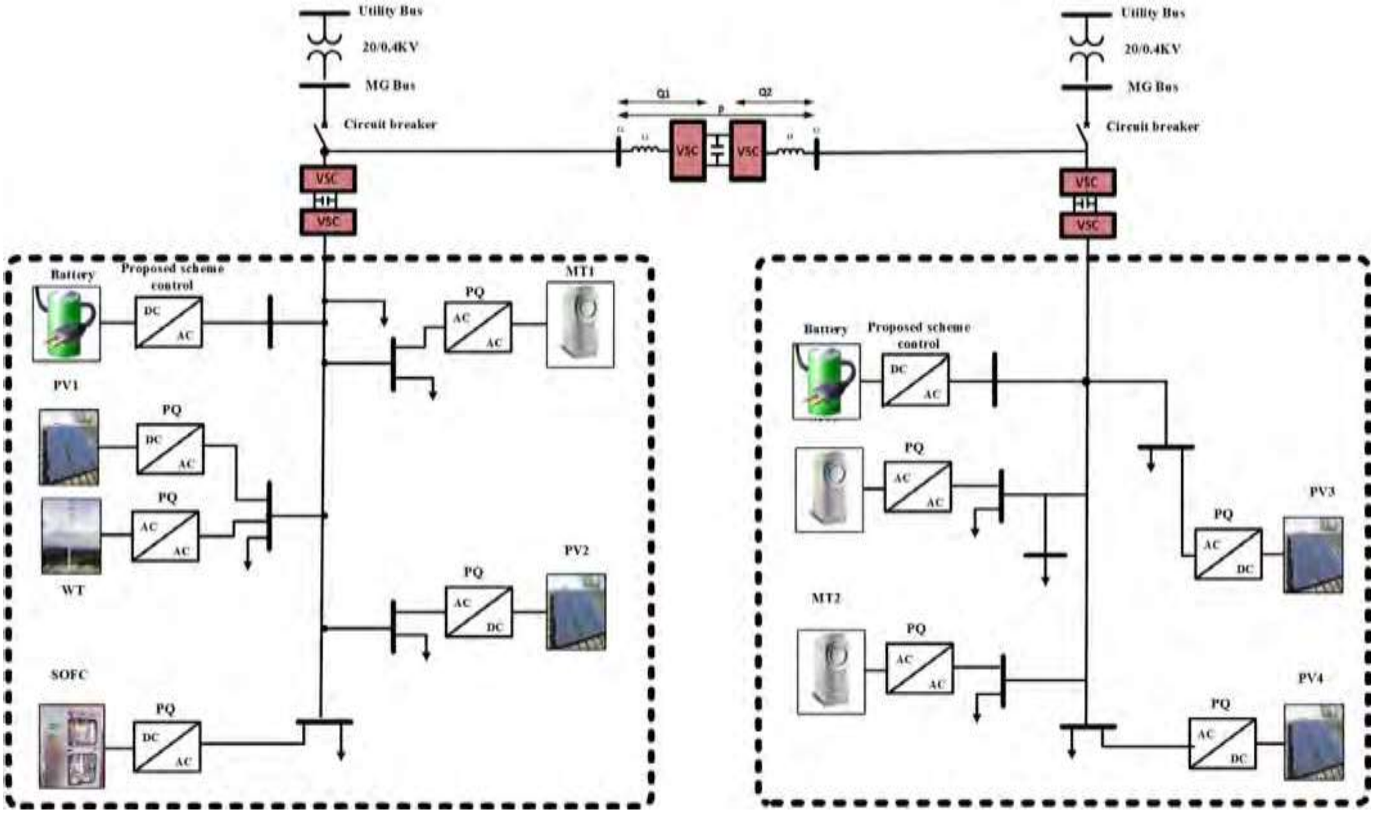

Fig. 1: Sample power system using BTB VSCs to manage congestion at the interlinking ties

IV. STRATEGY II: USING TCSC TO CONGESTION MANAGEMENT

In this strategy power electronic flexible devices are used to manage the exchange power between the microgrid and the upstream macrogrid. The best candidate in this regard is Thyristor-Controlled Series Capacitor (TCSC) [19-22]. The TCSC is dynamically controlled to stabilize the fixed amount of power to be exchanged by adjusting the reactance of the line. Some remarkable issues are needed here to be solved and attended; the resistances of the tie lines in distribution systems are not ignorable like transmission systems. TCSC has different operating characteristics, i.e., series controllable capacitor/reactor and protection modes in emergencies. Whenever the active power control is of primary concern, then the capacitance of the TCSC is so presented that by tuning the reactance of the line, the specified amount of active power is transferred for different operating conditions determined by the voltage phasors of the line ends. In this strategy, the congestion is managed by tuning the flow of the power according to the balance of the power of the microgrids. Here, the problem can be defined as optimizing the supply/demand of the microgrids based on the specified criteria such as economic dispatch and provide the balance from the utility grid and the adjacent microgrids.

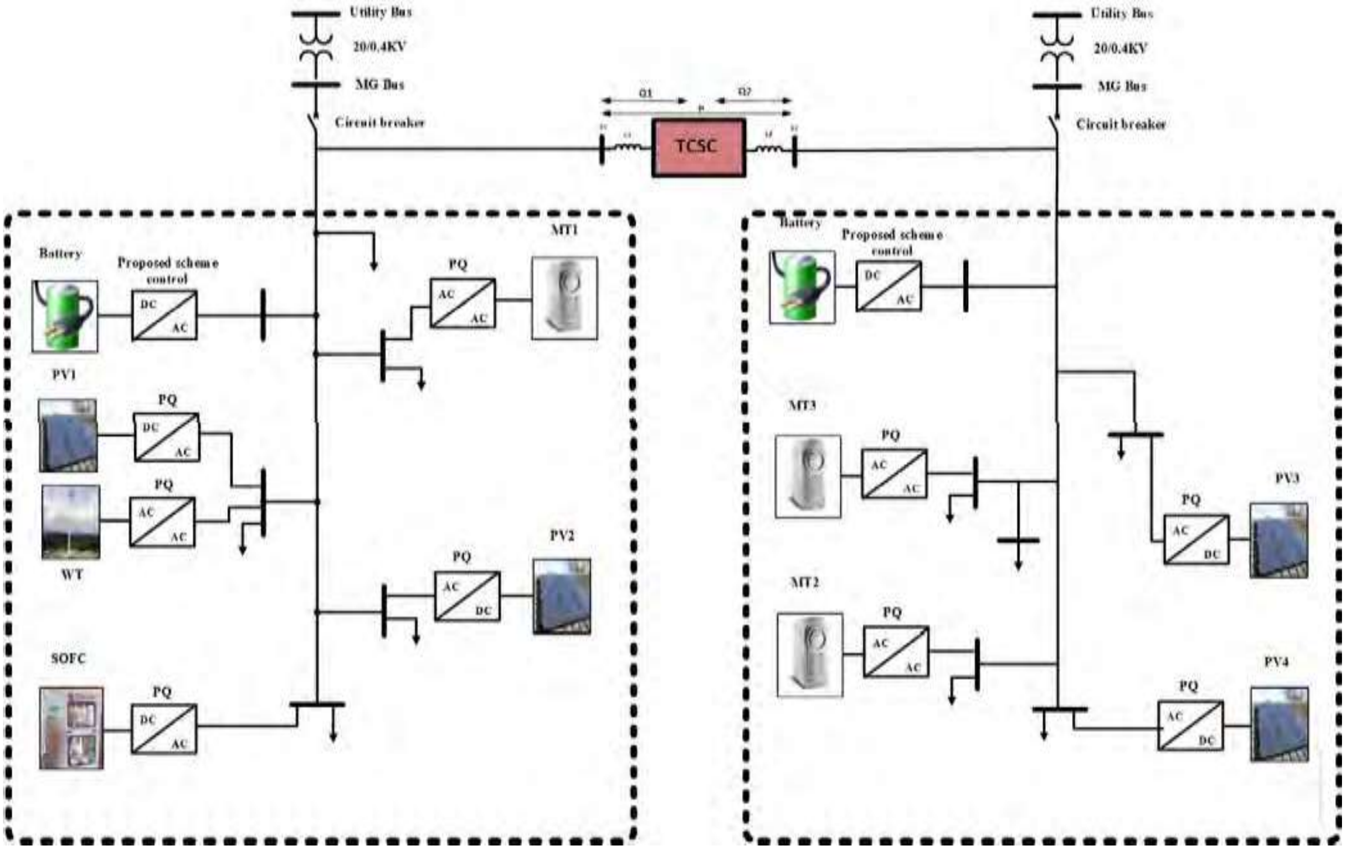

Fig. 2: Application of TCSC to congestion management in interconnection of different microgrids.

V. Strategy III: Using Communication Links to Manage Congestion

In this strategy no new installation are required but communication links to the DGs and some data regarding the power flows are required to implement a central controller in order to optimize the supply/demand in an intelligent method removing any unwanted congestion on the tie lines[23-26]. Proper management of the controllable resources would hopefully lead to an optimize power flow pattern that the congestions are minimized. This strategy needs two important points:

1) A communication infrastructure to assess the microsources and even the amount of consumption in real time in order to perform a sophisticated power dispatch and unit commitment to deal with the congestion of the interlinking lines. Hopefully, the communication infrastructure is a prerequisite in new smart grids, so its availability is improving progressively[27].

2) An on-line computation platform to calculate the economic dispatch and use heuristic patterns to alleviate the overload of the interlinking lines. This platform is not so complicated to implement as there is mature experiences from the transmission systems.

VI. Strategy IV: Optimal Switching (Reconfiguration) to Cope with Congestion Management

In this strategy the optimal switching is the basis for congestion management. This strategy also needs some kind of image from the network, so communication links are also necessary [28]. Optimal switching means to close or open different switches in order to change the routes to supply the loads. This strategy is not easily applicable to any combination of microgrids, as its prerequisite is to have enough paths and switches in order to be able to change the power flow pattern. This optimal switching is well known in conventional distribution systems and sometimes it is referred to as "reconfiguration" [27,28]. Reconfiguration has different applications like to supply the loads in critical situations or alleviate the overloading of some feeders. Here, reconfiguration would be used to mitigate the overloading of the tie lines between the microgrids and between the microgrids and the upstream utility grid. This strategy needs some heuristics.

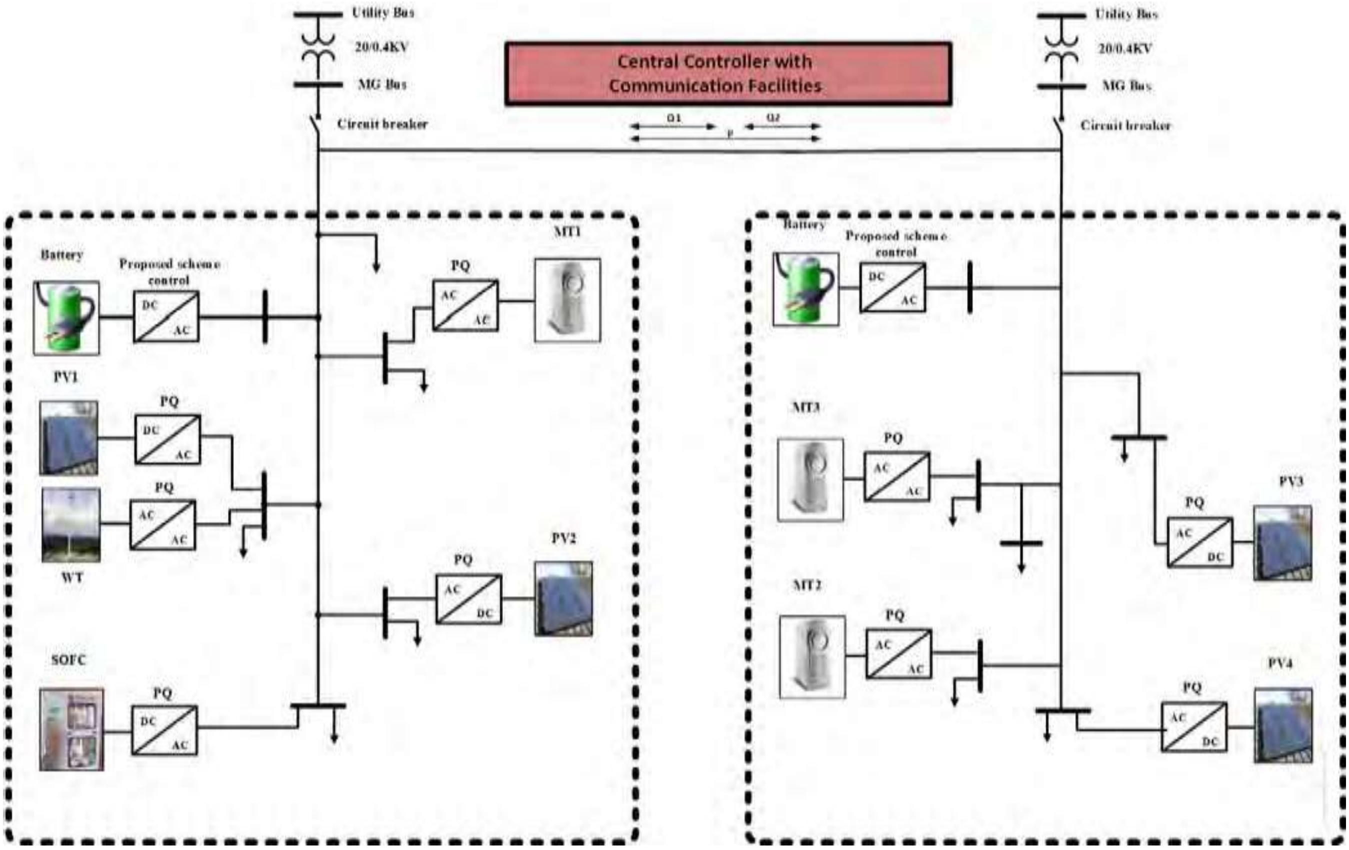

Fig. 3: Congestion management by using communication links and a central controller to dispatch power between different microsources.

VII. CONCLUSIONS

In this paper, congestion management is investigated for the interlinking tie lines connecting the microgrid to the upstream grid or the microgrids to each other. Four different strategies are proposed:

- ✓ BTB VSCs are used to interconnect any microgrid to the other microgrids/upstream utility network. This strategy is easy to be implemented but needs the required equipment and also sophisticated controlling algorithms to manage the through power flow.
- ✓ TCSCs are applied at the interconnecting lines. This strategy also needs the required equipment, but no communication link is required. This strategy is preferable from minimizing the power losses by reduction of the inductive reactance of the lines, although it is not so remarkable as the transmission lines.
- ✓ Communication links and an on-line computation platform are used to optimize the power flow of the tie lines. This method relies upon the communication infrastructure, which could be inherently available in future smart grids and microgrids.
- ✓ Reconfiguration is another strategy which could be used in complex systems with multiple paths for power supply. This method is preferable from applicability of the available experience of the conventional distribution systems.

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