Trial and service design document on FISMEP infrastructure

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ERA-Net Smart Grids Plus is an initiative of 21 European countries and regions. The vision for Smart Grids in Europe is to create an electric power system that integrates renewable energies and enables flexible consumer and production technologies. This can help to shape an electricity grid with a high security of supply, coupled with low greenhouse gas emissions, at an affordable price. Our aim is to support the development of the technologies, market designs and customer adoptions that are necessary to reach this goal. The initiative is providing a hub for the collaboration of European member-states. It supports the coordination of funding partners, enabling joint funding of RDD projects. Beyond that ERA-Net SG+ builds up a knowledge community, involving key demo projects and experts from all over Europe, to organise the learning between projects and programs from the local level up to the European level.

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1 Introduction

The overall goal of the field test Germany of the FISMEP project is the virtualization of Medium Voltage (MV) grid automation to the cloud.

In particular, the Medium Voltage grid consists of the multi-terminal DC network that RWTH, FEN GmbH and a group of key industry partners are realizing in the RWTH campus according to the Forschungscampus P4 project.

Moreover, the development of automation architecture for hybrid distribution networks, in which AC and DC sections coexist, is a central purpose of this work package.

The virtualization involves the FISMEP cloud platform, developed in the OpenStack server of RWTH, and it is constituted by software components according to the FIWARE framework.

FIWARE includes open source components, which can be assembled together with other third-party platform components to accelerate the development of smart solutions. Its application is perfectly suitable in the energy sector.

In addition to the FIWARE components, other software elements are included. They are developed in the FISMEP project and relate to specific applications for the automation of MV distribution grids.

The second chapter of this document provides significant information about the MVDC research campus grid; the electrical scheme and its components are described, together with the communication architecture toward the FISMEP platform and the related features.

The third chapter concerns the hybrid AC-DC medium voltage grids. Specific applications for the network management are presented, which are being integrated in the FISMEP cloud platform.

2 Medium Voltage DC research grid

The construction of FEN research grid is the main purpose of Forschungscampus P4 project. The Fig. 1 shows the electrical scheme of this network.

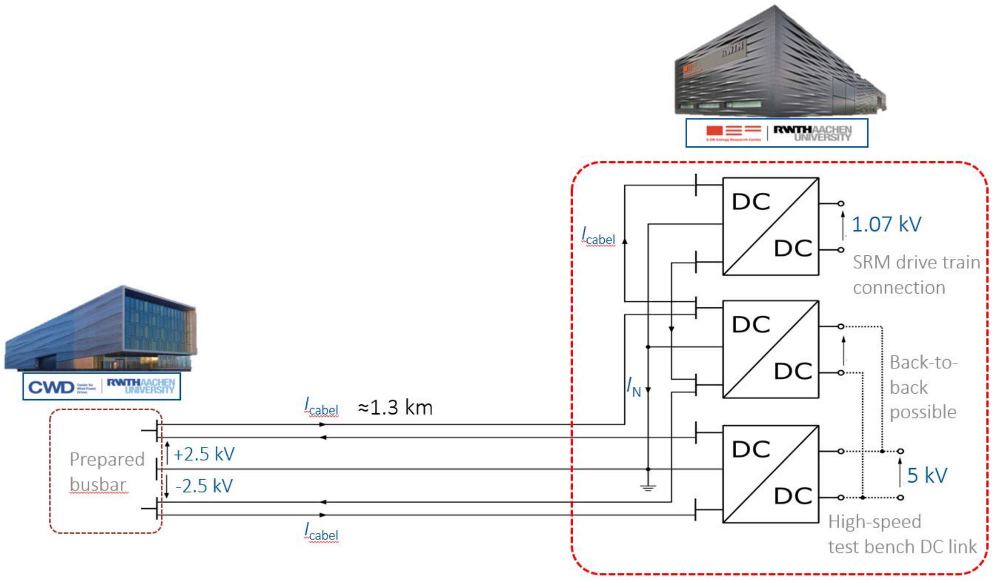

Fig. 1 Scheme of the FEN research grid.

The multi-terminal grid is constituted by three DC-DC converters: Dual-Active Bridge (DAB) topology with galvanic isolation and voltage transformation.

The converters are located in the same switchgear, which also hosts devices for protection, switching and measuring purposes.

Electrical cables with bipolar voltage level (two cables per phase) and a grounded neutral point connect the switchgear with a prepared busbar, at a distance of 1.3 km, which can host additional loads.

The details of the MV switchgear containing the DAB converters is reported in Fig. 2.

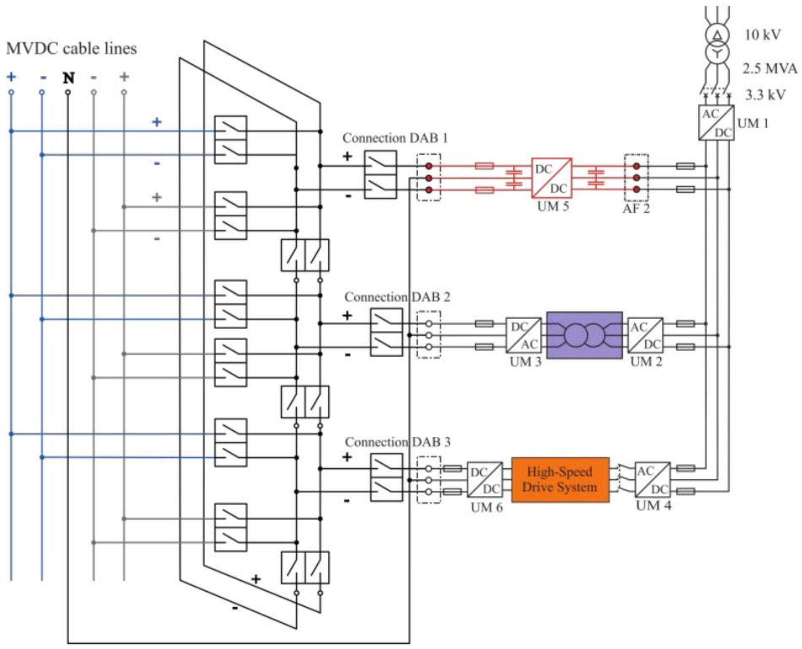

Fig. 2 Electrical drawing of the MV swicthgear

The control of switching devices allow the connection of each converter to a specific electrical line; in addition, the converters can be disconnected each other by operating the series switches.

A transformer coupled with an AC-DC converter constitutes the AC interface to the MVDC network. The DAB converters can be exchanged between them, to test new configurations, and the back-to-back connection is possible.

The grid is used to test concepts for the control and stability of multi-terminal DC systems as well as components (like the DC-DC converters) in the grid in real operating conditions.

2.1 Communication architecture

The measurement of electrical quantities in the MVDC network are provided by current and voltage sensors (transducers) installed on the busbars and by converters sensors.

Since the protection against overcurrent and short-circuits is performed by the converters themselves, the measurements are used to develop a supervisory control and data acquisition (SCADA) system.

It is constituted by an Human-Machine Interface (HMI), located in the FEN GmbH facilities, which allows the monitoring of all electrical variables and the status of the network. Moreover, it is possible to control the powering and the setpoints of DC-DC converters, together with the position of the switching devices.

The measurements are collected by an Intelligent Electronic Device (IED) installed in each panel of the switchgear: in particular, the real-time industrial controller CompactRIO (produced by National Instruments) is used.

Each CompactRIO is equipped with IO modules that acquire the measurements coming from MV transducers and DAB converters.

From each converter, the current and voltage at both sides, the phase shift, the status and message errors are collected. The CompactRIO provides the reference power, as setpoint, coming from the SCADA system.

The communication between the CompactRIO and the SCADA system, or a Substation Automation Unit (SAU), is based on IEC 61850 protocol (shown in Fig. 3); particularly, the Manufacturing Messaging Specification (MMS) is adopted.

This implementation requires to configure the IED structure according to logical nodes; each of them is associated to a specific functionality (measurement, controller parameters, protection, etc.).

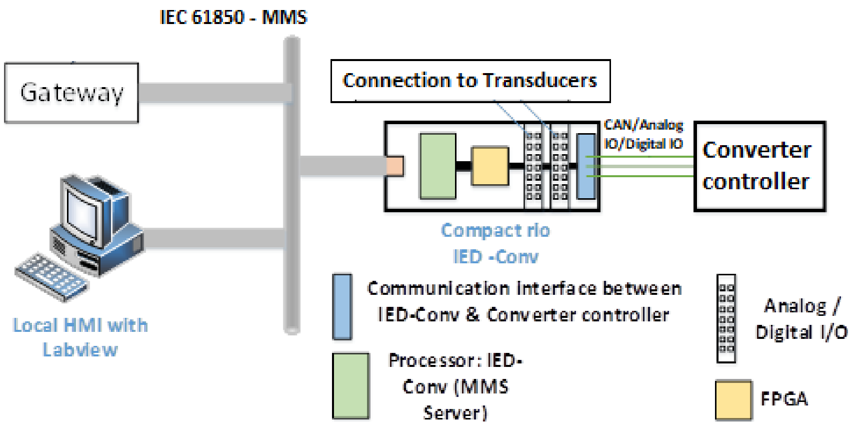

Fig. 3 Communication architecture with CompactRIO

2.2 Integration of FISMEP platform

The integration to the FISMEP platform is realized by acquiring the same data from the CompactRIO, which are normally exchanged with the SCADA system of FEN.

Since the data are provided according to the IEC 61850 – MMS protocol, it is necessary to use a gateway component to interface this communication protocol.

The gateway VillasNode, from the Institute for Automation of Complex Power Systems of RWTH Aachen [1], is being implemented to translate the MMS data into MQTT information model.

The Fig. 4 shows the communication architecture between CompactRIO and the FISMEP platform; moreover, the FIWARE components that constitute the platform are represented.

The Orion Context Broker manages context information and its availability. It is possible to create context elements and manage them through updates and queries. In addition, notification are provided when context elements are modified [2].

The data can be visualized using the open software Grafana, which interacts with the Orion Conext Broker. Specific alerts can be deployed (e.g., in case a measurement quantity overcomes the assigned limit) or a better understanding of the system with respect of the time evolution [3].

Big Data Analysis – Cosmos is the third FIWARE Generic Enabler (GE) that is included in the proposed FISMEP platform. It allows the evaluation of both batch and/or stream data. Batch data do not need immediate processing and they can be stored; in the specific FEN MVDC grid, they can be related to the electrical load condition. On the other hand, the stream data require the instantaneous analysis. They are associated to voltage level on the two sides of each converter, in order to detect their excessive variation, or the status of components (connected and operative).

At the time of elaborating this document, these components are being tested and integrating between them, to fulfill the described functions.

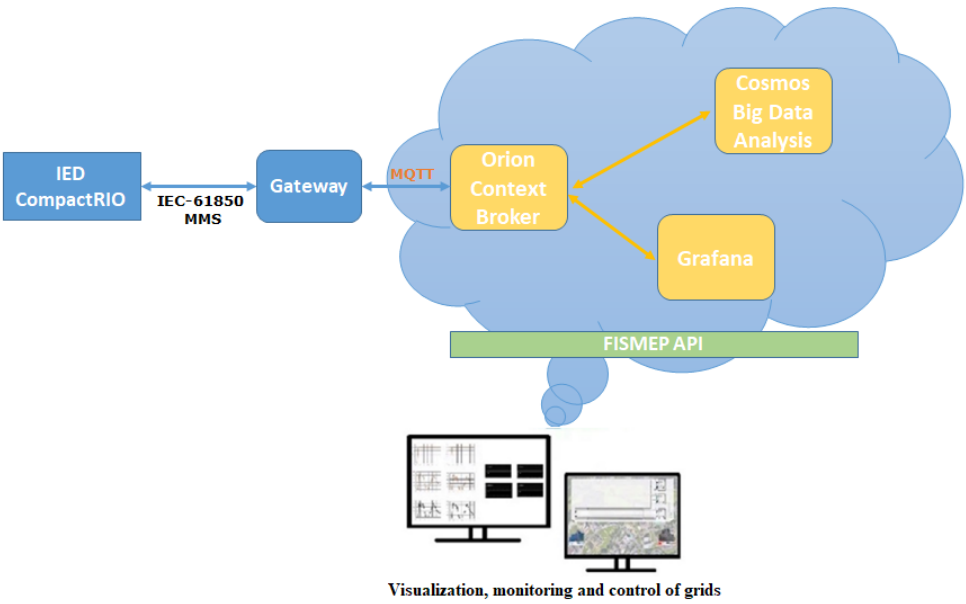

Fig. 4 Acquisition of CompactRIO data in the FISMEP platform

2.3 Features of the FISMEP platform

As anticipated in the previous paragraph, the main goal of data collection from the FEN MVDC grid is the use of a SCADA system: it allows the visualization, monitoring and control of the grid in real time.

The electrical quantities that are monitored include voltage, current and phase displacement of the DC-DC converters; with these values, the overall flow of power and energy in the grid can be provided.

The control indicates the power or voltage set-points of the converter, together with the connection/disconnection of loads (that will be placed in the prepared busbar) and the power on/off of each converter.

These functionalities are accomplished by the FISMEP platform; in particular, with respect to the architecture description in the last paragraph, the interface with the user is represented by the Grafana component.

In addition, the historical data are available and accessible. By using them, the voltage profile or the energy consumption can be monitored in time-based graphs. Moreover, it is possible to choose between different time frames (e.g., last hour, last day or last week).

Successively, according to the next developments of the FEN MVDC grid and integration of new power devices, additional features can be deployed.

3 Medium Voltage AC-DC grid

As introduced at the beginning of this document, the development of automation for hybrid distribution networks is a goal of the FISMEP project.

An hybrid network is an electrical network in which traditional AC (alternate current) sections coexist with DC (direct current) sections. In order to interface these two portions, the AC-DC converters are deployed.

The existence of AC-DC grids in medium voltage relies on the continuous deployment of Distributed Energy Resources (DER), which can be represented by renewable power plants, and the parallel spread of Medium Voltage DC loads, as DC microgirds or electric vehicles (EV) charging stations.

Due to the cost of energy transport and transformation (from DC to AC, and reverse), multiterminal MVDC networks represent a suitable solution. Consequently, their co-existence and power exchange with the traditional AC grid has to be analyzed.

In the FISMEP project framework, studies on grid management are carried out. This research activity is direct to network configuration in healthy and faulted conditions. Since the hybrid AC-DC grids are analyzed, the work includes control of power flow between the AC and DC sections of the grid.

In the following paragraphs, service restoration and network reconfiguration methods are presented, together with the integration to the FISMEP platform.

3.1 Service Restoration

When a fault occur in an electrical grid the protection system has to act in the fastest way possible, according to the selectivity scheme, to open the circuit breaker that are directly upstream and downstream the fault location. In this way, the faulted area is isolated and the power distribution can continue.

Since the distribution systems are managed in radial configuration, in which the power flow is unidirectional and each load is fed by only one substation, the nodes downstream the fault are no energized anymore, even if they are located in a healthy portion of the network.

Considering the Fig. 5, in which the black squares represent the closed switches and the white squares indicate the open ones, the fault occurs in node A1 and, consequently, the circuit breakers 1,2,3 and 19 trip. As result, the nodes with green circles are no energized anymore.

A Rule-based optimization (RBO) service restoration algorithm has been defined and implemented. The goal is the re-powering of the de-energized nodes one by one, by determining which primary substation is more suitable to power it and sending a closing command to the related bus-tie switch.

A bus-tie switch is the normally open circuit breaker that, in the radial systems, interconnect two different feeders.

The load considered as target for the service restoration is chosen according to a priority index, which is a particular attribute of the nodes. In fact, critical infrastructures (e.g. hospitals, transport system, dangerous energy sites, etc.) need to be re-powered in the shortest time possible.

The Dijkstra’s algorithm is a graph theory algorithm to determine the minimum path between two nodes in a graph. In our case, it is applied between each primary substation (iterated one by one) and the selected target load.

For each existing reconfiguration path (i.e. for the path between each substation and the target load) it is necessary to compute its suitability, namely the respect of the following constraints:

1. Respect of thermal limit for electrical lines current
2. Respect of nominal voltage level
3. Respect of network radiality

The electrical quantities of the network, necessary to verify the respect of constraints, are computed by applying a weighted least square (WLS) state estimation approach.

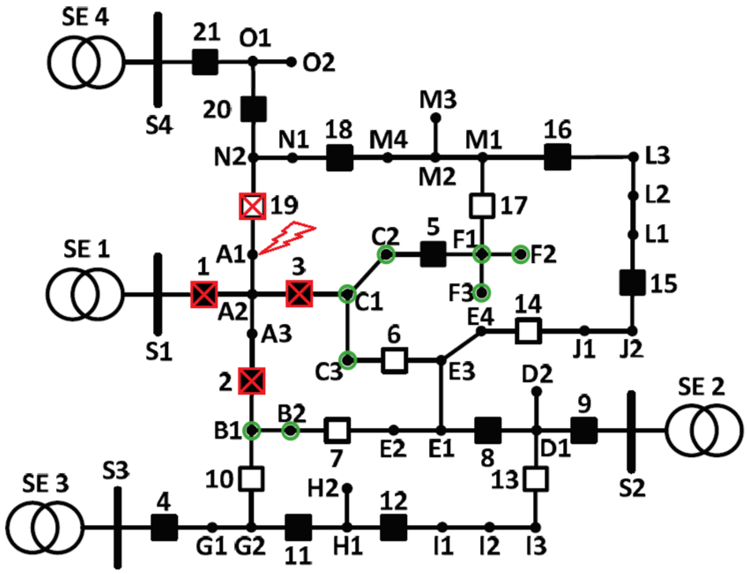

Fig. 5 Example of MV faulted grid for the application of service restoration

Once the restoration paths that do not respect the constraints are discarded, the best restoration scheme is determined.

This is realized by taking into account the power losses and the utilization of electrical lines (i.e. the current flowing in a line with respect to the line ampacity). These two aspects are summarized in the indicator k, computed with the following formula:

$$k = \frac{u_1}{P_{load}} + \sum_{i=1}^{m} u_{i+1} \cdot \frac{I_{max}}{I_{max} - I_i}$$

In which the terms $u_{1\dots m}$ represent a weighting factors for which the user can decide if the target of the restoration is more oriented toward the reduction of power losses or minimization of line consumption.

P_{load} represents the active power of all the loads in the configuration, I_{max} is the ampacity of the considered conductor and I_i is the actual current flowing in one of the m line.

The different values assigned to u_{i+1} factors cause high importance to the most consumed lines (in which the ratio $\frac{I_{max}}{I_{max}-I_i}$ is high).

The substation that will carry out the service restoration is the one having the lowest k indicator. Then, the corresponding bus-tie on the restoration path is closed.

For example, considering the situation in Fig. 5, the restoration of load B2 (taken as target) can be carried out by closing circuit breaker 7 or 10 (powering from SE 2 or SE 3, respectively).

Once a load is restored, the process is repeated until all the de-energized loads are powered or the constraints are violated.

With respect to the example in Fig. 5, once B2 (and consequently also B1, which is electrically connected) is restored, the algorithm finds the optimal path to restore the loads in the remaining de-energized branch (from F1 to C3) by closing or switch 6 or 17.

3.1.1 Integration to FISMEP platform

The described algorithm has been developed in Python 3 code and using an SQL database, which emulates the distribution grid operator (DSO) control center that receive information from all filed devices.

By using the state estimation approach, each field measurement is considered and weighted according to its uncertainty, making the algorithm suitable for real-time application and able to follow each variation in the network.

The real-time simulations provide suitable results: the service restoration for grid in Fig. 5 lasts 3.53 ±0.19 s; it proves to be suitable for active distribution grids (that include DERs) in which the restoration of critical loads is the main goal.

The algorithm can be easily adapted to traditional AC grids or hybrid AC-DC networks, that includes multiterminal DC sections (in this case, the state estimation considers the load injection at the AC-DC converter interface).

The proposed RBO state estimation is integrated with the FISMEP platform by considering the Orion Context Broker as database (DSO control center), from which the grid data are retrieved and to which the closing command for the selected bus-tie is sent.

The single line diagram of the network and all the information about switches, loads and electrical quantities can be shown using the Grafana component.

3.2 Network Reconfiguration

As described above, the distribution grid is managed with radial structure, in which the sources of power (primary substations) are electrically disconnected each other. The only element that interfaces the different feeders is the bus-tie unit.

The electrical networks are becoming more and more complex due, for example, to the inclusion of DERs, prosumers (customers that can absorb or produce electrical energy, injecting it into the grid) and new feeders that are installed. As consequence, the power flow profiles change more and more during the considered time frame.

For this reason, a specific network configuration could not be optimal with respect to the actual power flow (with the specific load and DERs power injections/generations). The configuration of the grid can be modifying by acting on the switch statuses: opening and closing them, always keeping the radial structure.

The proposed algorithm retrieves the actual grid data and considers all the possible configurations, applying a power flow approach to each of them.

Since having a grid with with n nodes means 2^n possible configurations, causing a too high computation time, the number of feasible configurations is reduced by considering only the radial structures. This is realized by knowing the number of circuit breakers, nodes and substations in the grid. The result of this method is the fixed number of closed/open circuit breakers (over the total).

The analysis is carried out by using the open software PYACDCPF [5], which allows to compute the power flow for hybrid AC-DC networks.

A grid with 40 nodes has been modelled, with four primary substations in the AC section and a multiterminal DC grid that is interfaced by three AC-DC converters.

After the constraints about voltage level in the nodes and thermal limit in the electrical lines have been verified, the algorithm selects the configuration with the minimum power losses.

The proposed network configuration is implemented (by changing the switches statuses) if the number of switching operations in the selected time frame is below a specified limit. With respect to this last point, the load and generation forecasts are taken into account to determine the number of switching operations that will take place.

As the service restoration, also the network reconfiguration can be deployed using the Orion Context Broker as database and interface between the algorithm and the field devices.

3.3 Model of the hybrid AC-DC grid

The hybrid grid that will be used for the validation of the automation algorithms in the FISMEP project will be developed by using the Real Time Digital Simulator (RTDS) present in the laboratories of Institute for Automation of Complex Power Systems (ACS) of RWTH Aachen university.

The grid model, which is being realized and validated at the time this document is prepared, is suitable for the real time testing of service restoration and network reconfiguration algorithms described in the previous paragraphs. Hence, it contains circuit breaker in AC section, lumped power injections/generations (representing loads or DERs) and power transformers of the primary substations. The DC section will include loads or distributed generation components.

A great importance is assigned to the AC-DC converters that interface the two grid sections. The Fig. 6 represents their model, as Voltage Source Controlled (VSC) converter, in the AC side [6]. In addition to the controllable voltage source $\bar{U}_C$ there is the reactor impedance $\bar{Z}_C$, the filter indicated by the susceptance B_f and the transformer impedance $\bar{Z}_{tf}$.

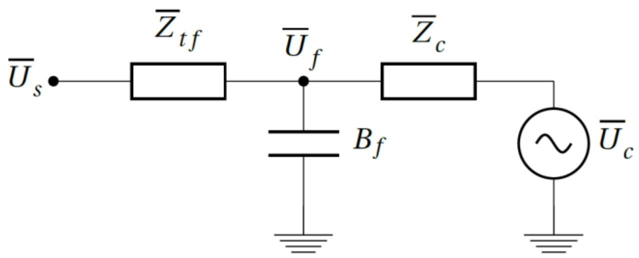

Fig. 6 The AC-DC converter model in the AC section

The control of the converter, in the DC section can be performed according to constant power control, constant voltage control or droop contro. Using PYACDCPF it is possible to choose between the different control modes; in the RTDS model, specific control schemes are deployed.

The AC-DC grid model will be interfaced to the FISMEP platform by using the VillasNode gateway, in a similar way to the CompactRIO for MVDC research grid, and the field data (voltage nodes, line currents, switch statuses, etc.) will be subscribed to the Orion Context Broker; in this way, they will be ready to be used by the proposed algorithms.

4 Conclusion

In this trial and service design document, related to the work package 4 (Field Test Germany) of the FISMEP project, the achieved developments and progress of activities are presented.

Considering the two aspects of the work package, the development of automation for DC and hybrid AC-DC Medium Voltage grids, the trial test refers to the MVDC research grid of FEN Forschungscampus P4 project and the hybrid AC-DC grid model that is realized in the RWTH laboratory.

The integration with the FISMEP platform is carried out by providing the grid data via a gateway element. These data are, then, analyzed and visualized with specific FIWARE components. It allows the grid monitoring in the MVDC research grid and the testing of developed network management algorithms for hybrid AC-DC networks.

Additional features can be included, by integrating new FIWARE components or different enablers, and the grid model is feasible for diverse algorithms that require validation via real time simulations.

5 References

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