

Implementation of an urban distribution system digital twin in real time

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I. INTRODUCTION

As *International Renewable Energy Agency* (IRENA) has estimated, Renewable Energy Sources (RES), together with demand reduction and energy efficiency, could account for over 80% of the CO₂ emission reductions needed for reaching the goal of limiting global temperature rise well below 2°C. Despite RES are an enabling technology, their large penetration involves some issues, like short-circuit currents increasing, lack of inertia/damping and voltage profile modification. For these reasons, it is of utmost importance to be able to predict the impact of RES on the electricity grid. The work presented in this M.Sc. Thesis aims to analyse the implementation of a digital twin of a portion of the electrical distribution grid of Turin in order to emulate the real behaviour of the network. The implementation is carried out in the RTDS® Simulator, the real-time simulator made by *RTDS Technologies Inc.*, which is located in the *Energy Center Lab* of Politecnico di Torino.

II. DIGITAL TWIN AND SIMULATION

The simulated grid is a digital twin of a portion of the distribution network supplied by Stura primary substation. The High Voltage (HV) grid is replaced by its Thévenin equivalent circuit with a nominal voltage of 220kV. The Medium Voltage (MV) network is radial operated at 22kV and it is composed by 53 nodes. Moreover, two secondary substations are included. The Low Voltage (LV) grid is radial with a nominal voltage of 0.4kV and composed by 27 nodes. The digital twin is implemented by using the components included in RSCAD® libraries. The parameters set were provided by an Italian Distribution System Operator (DSO). The distribution cables lines are simulated by using the Pi-equivalent circuit. For MV and LV load, a voltage-dependent model is used. In particular, the *exponential load model* is chosen. According to it, the instantaneous value of active and reactive power components are expressed by the algebraic functions below:

$$P_{set} = P_0 \cdot \left(\frac{V}{V_0} \right)^\alpha \quad Q_{set} = Q_0 \cdot \left(\frac{V}{V_0} \right)^\beta \quad (1)$$

The exponents α and β were chosen based on the load aggregate type and are provided in Tab.I.

Table I: Coefficients of the *exponential load model*

| Aggregate/Type | α | β |
|----------------|----------|---------|
| Residential | 0.92 | 4.04 |
| Commercial | 1.51 | 3.4 |
| Industrial | 0.18 | 6 |

P and Q set points per each load can be provided to the P_{set} and Q_{set} input wires of the RSCAD® load component and are computed by using the control block scheme like the one shown in Fig.1.

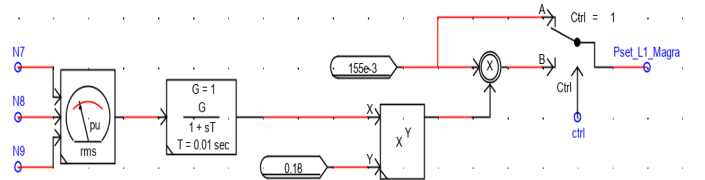


Figure 1: Block scheme for P and Q set point computation for an industrial load aggregate

For this simulation, the *Distribution Mode* is chosen in order to give the possibility to add other nodes and components to the grid, without computational problems. Basing on the components simulated, a simulation time-step of 150μs is sufficiently small for the evaluation to be done.

III. COMPARISON OF RESULTS

In order to evaluate the accuracy of the simulation, the results obtained with RTDS® Simulator are compared with the ones obtained with OPAL-RT® Simulator in which the same digital twin was implemented. The steady state solution and some electromagnetic transients due to faults at MV level are taken into account. As an example, in Tab.II a comparison between main branch currents in normal operating conditions is provided.

Table II: Comparison of current values in normal operating condition

| Branch | I_RTDS [A] | I_OPAL-RT [A] |
|------------------------|---------------|------------------|
| SRC - BUS 1 | 70 | 70 |
| TR_MagraBrenta - BUS 2 | 154 | 158 |
| TR_FiatGrosso - BUS 17 | 368 | 369 |
| TR_Chieri - BUS 36 | 172 | 173 |
| BUS 2 - NODE 3 | 46 | 47 |
| BUS 2 - NODE 7 | 108 | 111 |
| BUS 17 - NODE 18 | 172 | 172 |
| BUS 17 - NODE 28 | 198 | 198 |

IV. AUTOMATED PROTECTION SYSTEM

The protection devices installed in primary and secondary substation are shown in Fig.2.

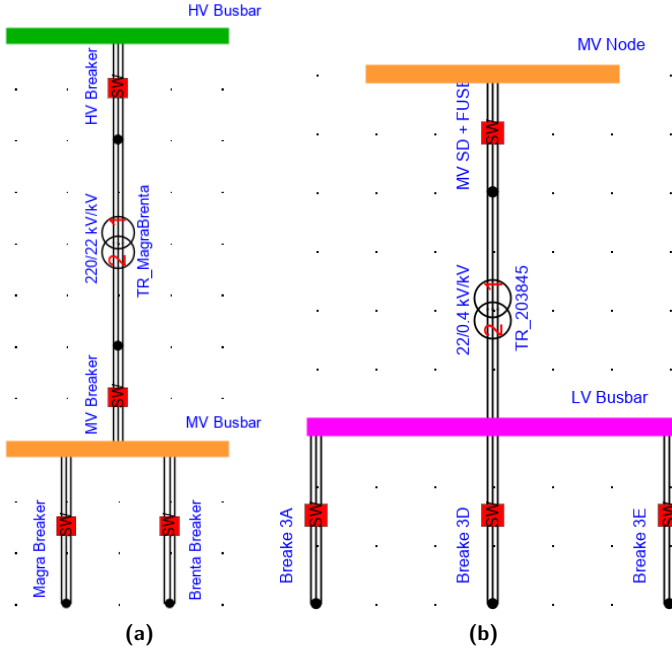


Figure 2: Protection system in: (a) primary substation; (b) secondary substation

The relays with which the various circuit breakers are equipped are listed below:

- HV Breaker: overcurrent protection 50/51T;
- MV Breaker:
 - overcurrent protection 51T;
 - overvoltage protection 59;
 - homopolar overvoltage protection 59N;
- Magra-Brenta Breaker:
 - overcurrent protection 50/51;
 - earth-directional protection 67N;
- Breaker 3A, 3D and 3E: overcurrent protection 49/50/51.

In secondary substation, as can be seen in Fig.2b, the MV/LV transformer protection is carried out by using Switch Disconnectors (SD) equipped with MV fuses whose size was chosen according to both the nominal current and the inrush one of the transformer. Moreover, the cross-sectional area of the LV lines cables changes along the LV feeders. In these cases, LV fuses are implemented for protecting the cables against overcurrent. The thresholds setting of the above-mentioned relays was done by following the guidelines of both *Terna S.p.a* and the DSO. Relays functionalities are simulated by using a control logic that trips the related circuit breaker when a threshold is exceeded. The time-current characteristic of the various relays is implemented by building block schemes made up of components included in RSCAD® *Controls* library. Each control logic is explained, in the thesis, through its flow chart whose an example is shown in Fig.3.

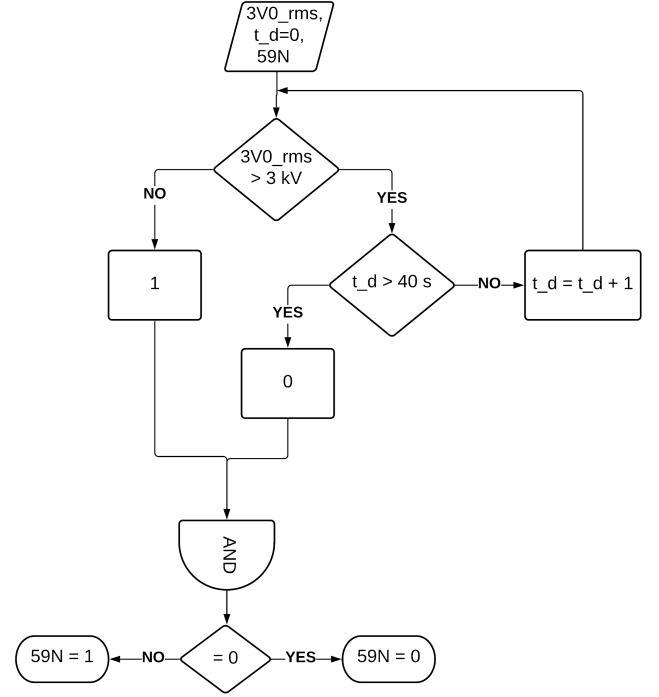


Figure 3: Flow chart of the control logic for relay 59N installed in MV breaker

V. SIMULATION RESULTS

In case of multiphase faults, the overcurrent protections trip the circuit breakers, since the fault current is very high. For protection against single-phase-to-ground faults, whose fault current is much lower than the previous case, the earth-directional protections are implemented. In order to verify the effectiveness and the correct functionality of the control logic of the protection systems, a three-phase fault and a single-phase one at MV level are simulated. Moreover, thanks to the manual disabling implemented in each relay, also the selectivity among the protection devices was proved. In *Runtime* environment of RSCAD® the operating time of the various circuit breakers is measured by taking into account the fault time instant. From simulation results, is deduced that all relays trip the related circuit breaker according to the delays and the thresholds set.

VI. CONCLUSION

The digital twin implemented works properly and so can be used both to add RES component for analysing technical issues and to study other types of electromagnetic transients concerning the power system. Moreover, thanks to real-time simulation, both Power and Control Hardware-In-the-Loop (PHIL and CHIL) simulation can be done by using the digital twin implemented as the electricity grid with which to interface a real component without the risk that it can be damaged during the tests.