Distributed Generation Control via Ripple Signaling for Establishment of Ancillary Services in Distribution Networks

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***Abstract*— This paper presents the methodology and describes the technology requirements for exploiting ripple signalling to control Distributed Generation (DG) in the Distribution Network. A part of the Greek distribution network with increased penetration of PV power plants is simulated, with and without ripple signalling control, for various operational scenarios. The results of the simulation scenarios indicate the PV plants were the ripple signalling control should be applied. The results also highlight the ancillary services of the proposed methodology for the network, such as the improvement of the voltage profile and of other power quality indices along the feeders. The first tests of the actual system on the real line are also demonstrated, showing also that the new method is highly reliable, inherently cyber-secure and data-privacy protective.**

***Index Terms* – Distributed Generation, Ripple signalling, Renewable Energy Sources, Smart Grid, Smart Microgrid.**

I. Introduction

MANY Distribution Network Operators (DNOs) had invested to cross grid lines (interconnected lines) between two main lines (Fig. 1), and had also invested to remote controlled circuit breakers at the edges, towards their effort not to de-energize significant parts of a grid line, during repair or maintenance works, and finally to comply with the SAIDI and SAIFI indices [1], [2]. After the integration of DGs into the grid, a main issue with great impact on the grid operation has been identified: The interconnected lines impact due to high penetration of DGs, which gives rise to three specific problems:

(A) The peak production of all the DGs of a line is allowed to reach up to 80% of the thermal limit of a line. When transporting the load and the DG to another line through the lines' interconnection, the substation actually feeds two lines in series. Thus, in the case of low consumption and maximum productivity of the two lines' DGs (such as a Sunday lunch time period), the new line will be forced to operate with reverse currents near or above its thermal capacity or even to the 120 % of its capacity (series connection). If there is such an unpleasant situation, then the line-feeder will trip.

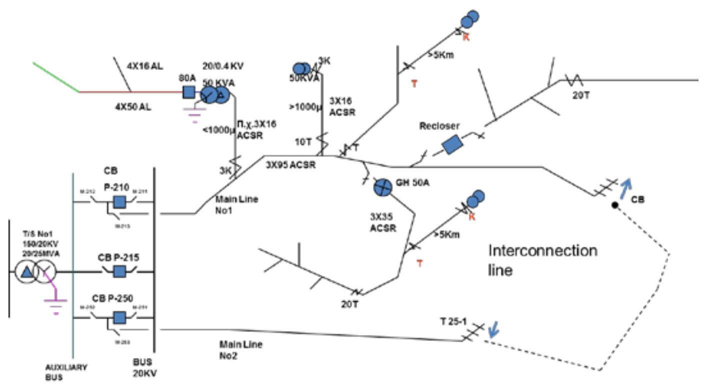

Fig. 1: Interconnection line example

(B) An even more serious situation is the level of the voltage along the "new line" which consists now of two main lines in series. It is certain that at the Network Connection Point (NCP) of many PV plants, the rms voltage value will reach or exceed the upper voltage limits, and the protection relays will de-energize too many PV plants. After three minutes (synchronization period in Greece), if there is a voltage reset within the limits, the PV plant will supply energy to the grid again, raising the voltage value at its NCP [3] again. If this raise exceeds the upper limit, it will be disconnected, and this situation will be repeated again and again, at many PV plants of the "new line".

(C) One third unpleasant situation may occur to the average voltage value at the consumers' facilities. The upper level of the voltage at the Point of Common Coupling (PCC) of a DG Unit is set to 253V at the low voltage (LV) grid and to 22kV at the medium voltage (MV) lines. If there is power production increase of DG units at the end of the "new line", and there are consumers at the same "neighborhood", these consumers will experience increased voltage levels as well, especially if the DG units are connected to the LV grid (too many roof PV stations, or DG connected to the LV network) (example of voltage curve with min and max DG at Figs. 2, 3). This situation is also verified by results of simulations that are conducted by the authors in [4].

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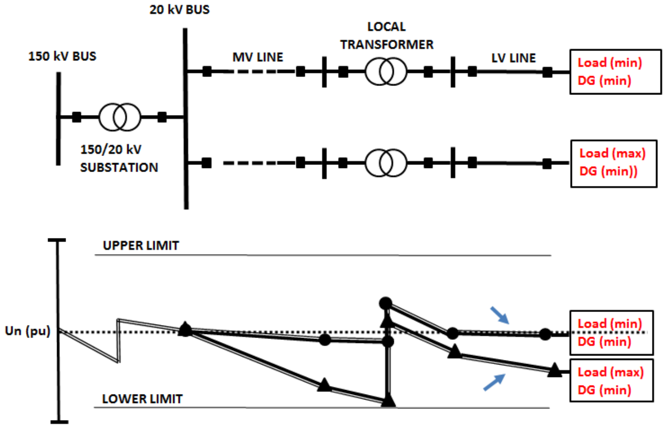

Fig. 2: Voltage profile including minimum DG penetration with min and max load situation

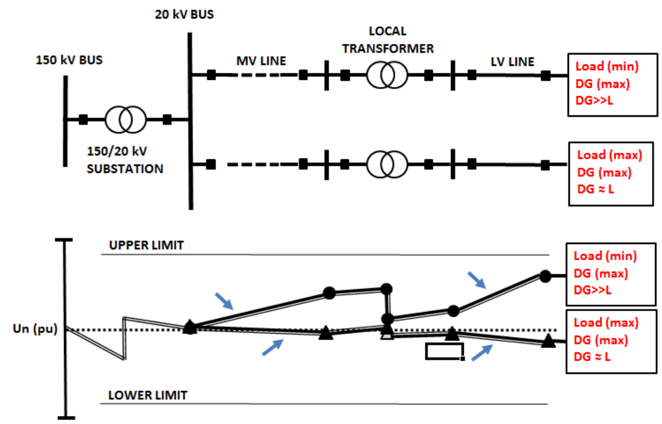

Fig. 3: Voltage profile including maximum DG penetration at min and max load situations.

The Hellenic Distribution Network Operator (HEDNO) has subcontracted the University of Western Macedonia-Dept of Electrical & Computer Engineering, in order to set-up a pilot system on a part of HEDNO's MV network and simulate and test how the ripple signaling system can solve the aforementioned problems. This paper describes the first part of the project (development, simulation and first tests of ripple signaling). The main objective of this paper is to develop and simulate easy-to-apply (both technically and in legal terms) and cost-effective solutions that utilize the ripple signaling system of the DNOs, in order to execute operations on the distribution network without worrying about violating the grid parameters and reliability indices, both of the consumers and of the producers.

II. ADDRESSING THE INTERCONNECTED LINES IMPACT VIA RIPPLE SIGNALLING

Traditionally DNOs around the world, use the technique of injecting to the Distribution Network different frequency signals, in order to control the function of street lighting, tariff changeover, etc. They use a resonance circuit, to inject a frequency signal. The Hellenic Distribution Network Operator's (HEDNO) network uses the Pulsadis system [5], according to which a 175Hz carrier signal that carries pulses is automatically injected to the DN for 102.25 sec (Fig. 4). A number of appropriate receivers recognize when it is their turn to make an action (energize or de-energize some relay contacts). A pair of pulses, like the ones in Fig. 5 and Fig. 6, is used every time to energize and to de-energize certain receivers respectively. So, when at a specified time of the day a pulse is beginning to be injected for 1sec, followed by 2,75 secs of silence, all the grid's receivers are sensing the incoming coded transmission (telegraph), and at the end of the 2,75 secs of silence, the receivers are beginning to measure intervals of 1sec followed by 1,5sec silence [5], [6], [7], [8].

If one receiver was preset to recognize the sixth transmission period, as an "ON" action for it, when and if the transmitted telegraph includes a transmission at the sixth period, the receiver will recognize, e.g. that it has to close a relay, and turn on the city lights.

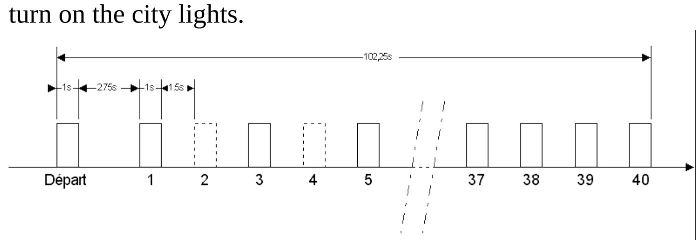

Fig. 4: Ripple control transmission telegraph

When, in the morning, another transmitted telegraph includes a transmission signal at the seventh time period, the same receiver, as preset, will recognize that e.g. it has to turn off the relay and thus turn off the city lights.

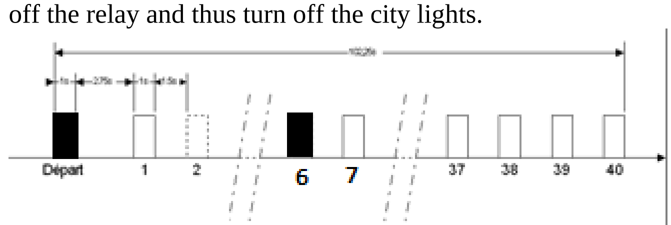

Fig. 5: Transmission of the pulse No6

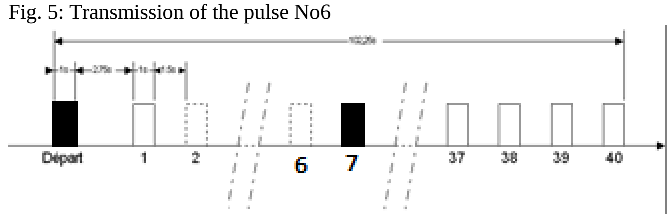

Fig. 6: Transmission of the pulse No7

The ripple control system can be used as follows:

All the modern PV inverters integrate remote control electrical contacts, and are ready for use by a ripple control receiver. Many of the PV inverters allow to be connected in groups of five to the same ripple control receiver [9]-[12]. To reduce more the cost of the ripple control receiver's installation, if there is a motorized central circuit breaker at the production side of the DG unit, we can operate it via its auxiliary I-O contacts. The main idea is to affect only the production side of a PV station, and not the auxiliary side in order to leave the PV station's area controlled by the owner (cameras, electric doors, fire detectors, internet connectivity, etc) (Fig. 7).

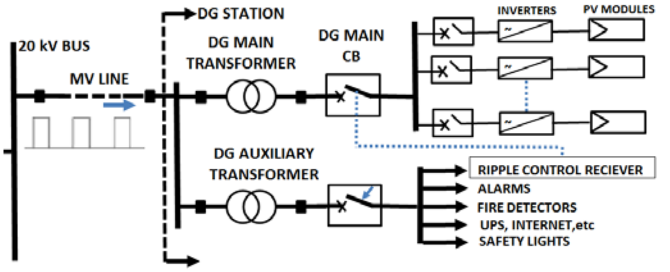

Fig. 7: Example of controlling the main circuit breaker of a DG via a ripple control receiver.

To avoid miss-operation of the transmitting system, such as disability of the DG to reconnect to the DN (which can raise legal issues), there will be a safety net, applying back-up solutions one by one or all together, such as:

i) There will be a preannouncement (to local papers, radio stations, HEDNO's site, sms or e-mail) of the ancillary service period, so everyone could be prepared to monitor the state of their DG station.

ii) To eliminate the possibility of "misunderstanding" of the signals by a receiver, we could use the traditional way of re-transmitting it after a few minutes.

The three specific problems that are mentioned in the Introduction Section above could be easily solved with the installation of ripple control receivers to every DG. Before the load and DG transfer to another line, with the help of the ripple control system, we can easily disconnect only the DGs of the line which is to be transferred. Therefore, the "new line" after the interconnection" will consist of the main line connected in series to the new line without its DG units (since they are disconnected after the ripple signaling) (Fig. 8).

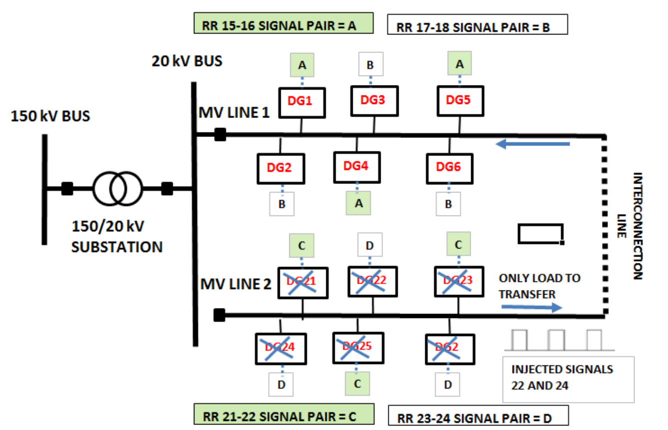

Fig. 8: Example of load transition from line 2 to the line 1, with DG disconnection at line 2

If this load transfer lasts for a long time period, e.g. 8 hours, some very helpful solutions are proposed:

i) By grouping the DGs after simulation studies, we can install different ripple control receivers at separate DGs groups (same receivers, programmed to act at different pair of signals), in order to disconnect or connect different group of DGs, with the biggest impact to voltage values (Fig. 9).

ii) By grouping the inverters in the same DG station and control these groups via different ripple control receivers (Fig. 10 below) or by installing one receiver per inverter (like Fig.11) and finally set a number of receivers to act like a group at the same pair of signals and the others like another group acting to different pair of signals we can disconnect a part of every station, thus decrease its power production. This operation can keep the voltage quality factors inside their limits, and fairly decrease the production of all the DGs of the "new line" (Fig.12). Similar techniques are proposed and tested by the authors in laboratory scale [13]-[16].

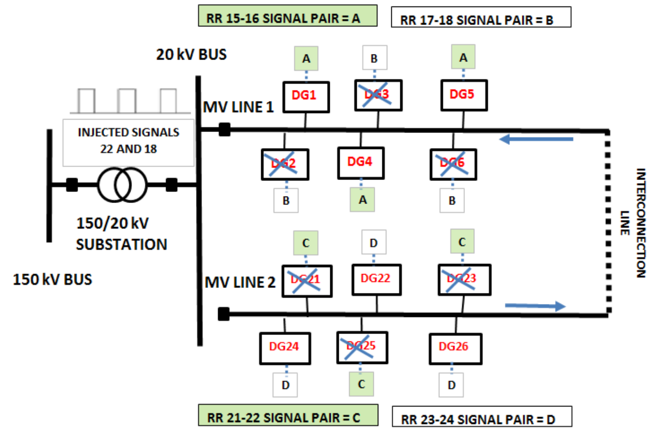

Fig. 9: Example of DGs in groups with different ripple control receivers, along load transition

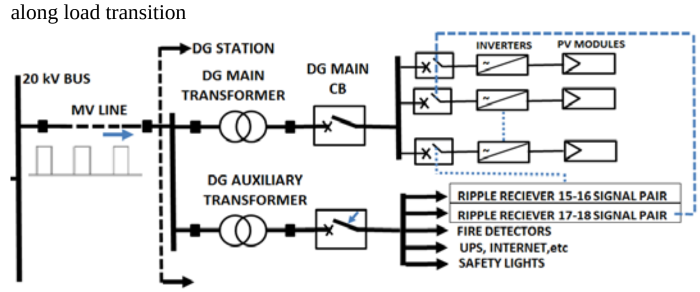

Fig. 10: Example of inverters in groups into the same DG station

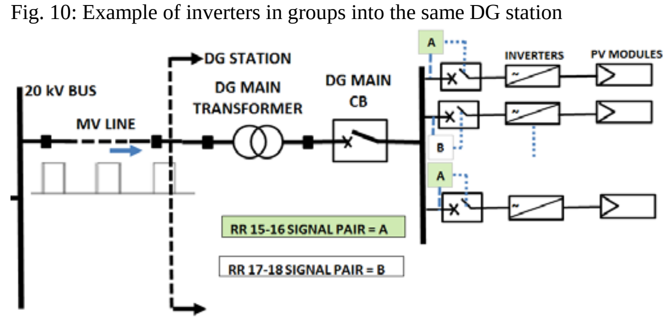

Fig. 11: Example of inverters in groups into the same DG station with one different receiver per inverter

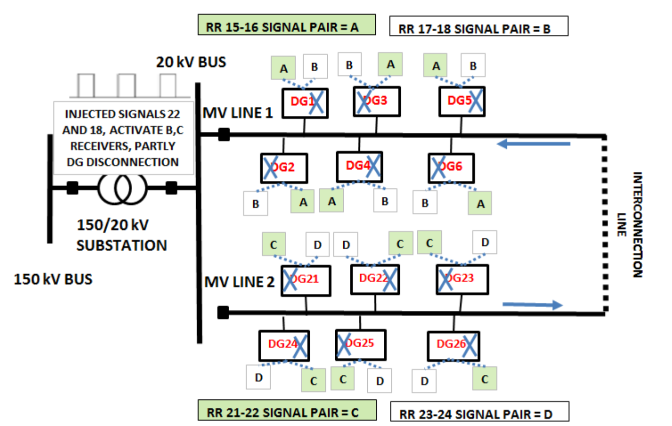

Fig. 12: Example of inverters in groups into the same DG station, and partly disconnection of inverters

III. DESCRIPTION OF THE MV GRID UNDER INVESTIGATION

The selection of the specific two main lines of Fig. 13 of the MV grid at the prefecture of Kastoria, Region of Western Macedonia in Northern Greece was based on the following criteria:

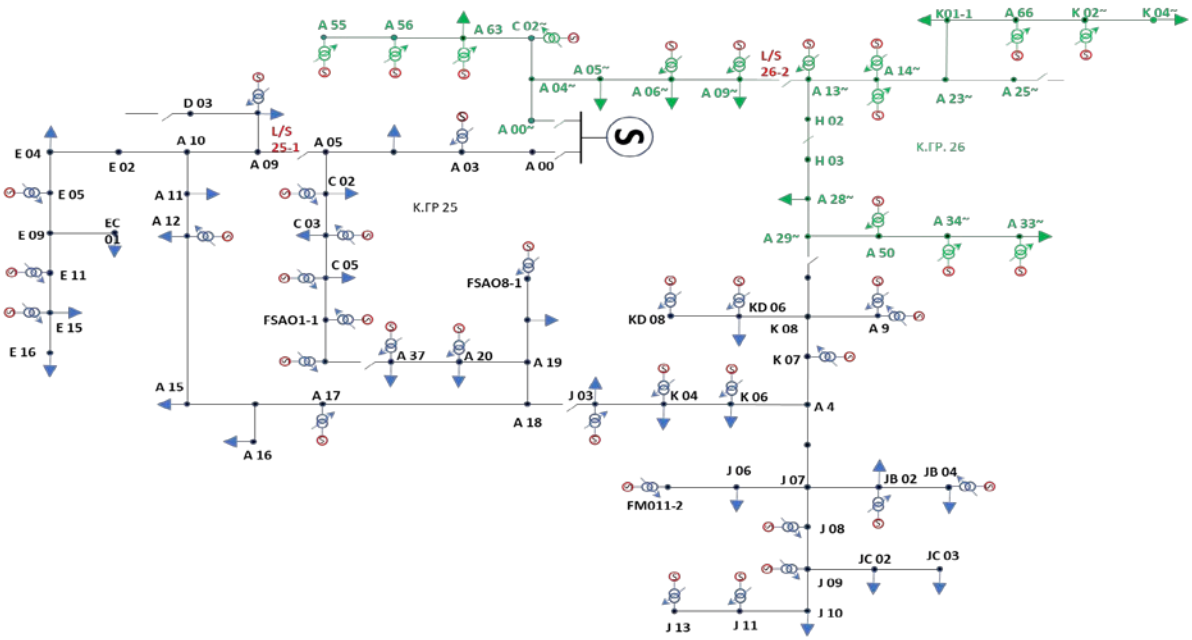

Fig. 13: The two selected MV lines: The black line is No25 and the green is No26. The red AC sources show where the PV distributed generators are located to.

1) These two lines are interconnected.
2) Both lines present maximum PV installed capacity, compared to other regular lines in Greece.
3) The cumulative PV installed capacity of both lines exceeds the thermal capacity of each line (when they are connected in series).

The peak daily power production of the PV producers of these two lines occurs at the same time with the usual network operations of the DNO during weekends.

These two lines obtain 169 connected PV producers, while 45 of them have installed capacity larger than 95 kWp each. The total installed capacity of these 45 producers reaches 15,879 MWp and corresponds to the 92 % of the total PV installed capacity of the two lines. Therefore, for the purposes of the simulation, it is proposed that only these 45 PV producers are assumed to be controlled by the ripple signaling, although all PV producers of the lines are considered during modeling and simulation.

IV. SIMULATION RESULTS

The modeling of the two lines and the simulation results were obtained by the respective software of the Greek DNO (HEDNO). Due to large amounts of DGs connected to the LV and MV parts of the lines, some parameters of the grid can't be measured accurately, and many load transfer operations are prohibited due to thermal capability or to voltage limits. In all simulated scenarios, the case of lowest recorded consumption is adopted (such as a Sunday lunch time period), since it is the worst case. During the simulations, the voltage of the main bus-bar of the two lines is set to the usual value of 20,7 kVs and 21 kVs. In all scenarios, we compare the voltage level of various nodes of the lines with and without the ripple signal control over the 45 PV producers. Four scenarios are the usual operations that occur due to scheduled maintenance works or due to grid reconfiguration because of a fault or due to underground cables works or because of adding new MV consumers to the grid. However, for saving space, only two of them are presented here:

A) Feeding part of line No 26 by line No 25, through their interconnection (Fig. 14): The ripple signaling in this case decreases the power production of the 45 PV producers to the 60 % of their actual production. From Fig. 15 it is obvious that with ripple signaling control, the voltage level of every node is below or equal to the limit of 22 kVs, which is not the case without applying ripple signaling, at the areas X of line No26 and Y of Line No25.

B) Feeding part of line No 25 by line No 26, through their interconnection (Fig. 16): The ripple signaling in this case decreases the power production of the 45 PV producers to the 60 % of their actual production. In this case, the voltage level of every node is below the limit of 22 kVs, which is not the case without applying ripple signaling, at the areas X1 and X2.

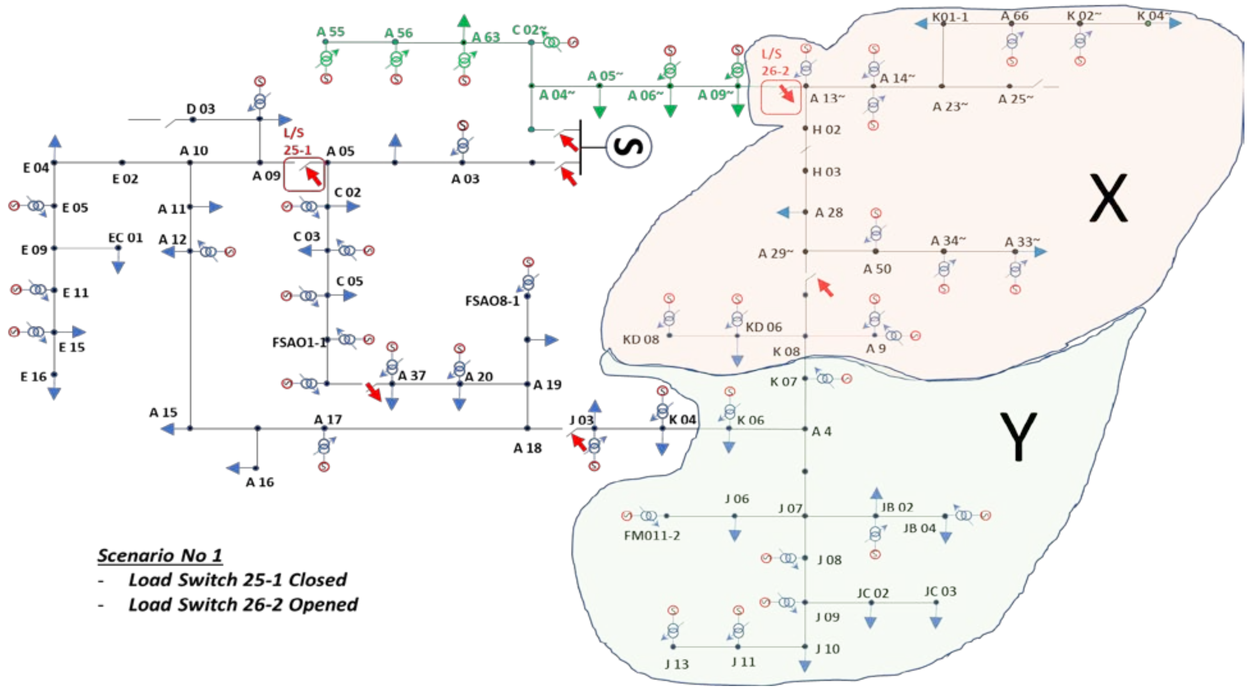

Fig. 14: Simulation scenario No1: The load switch 25-1 is closed and the load switch 26-2 is open. The X area is the part of line No26 that is fed by line No25 and the voltage level exceeds the limit of 22 kVs, in case of no ripple signaling control. The Y area is the interconnection part of line No25 where the voltage level exceeds the limit of 22 kVs, in case of no ripple signaling control.

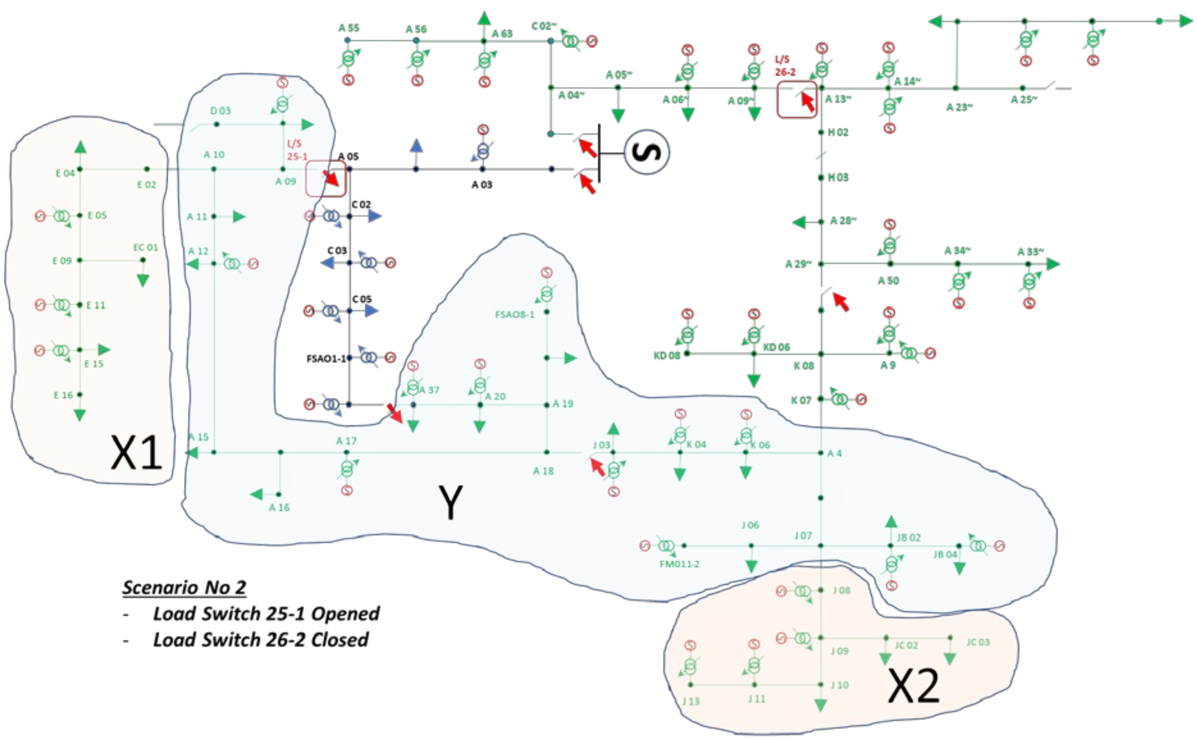

Fig. 16: Simulation scenario No2: The load switch 26-2 is closed and the load switch 25-1 is open. The X1 and X2 are the areas where the voltage level exceeds the limit of 22 kVs, in case of no ripple signaling control. The Y area includes voltage levels almost 22 kVs.

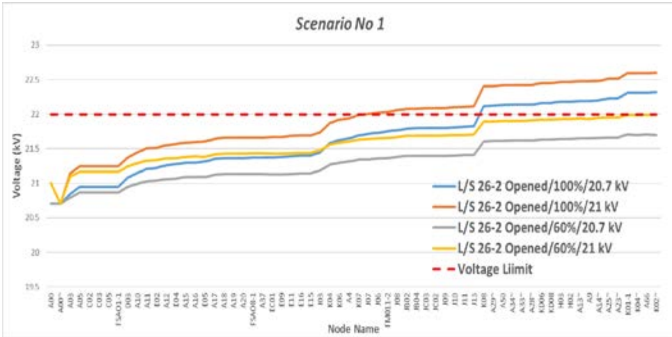

Fig. 15: Voltage profile of simulation scenario 1.

V. CONFIGURATION OF THE RIPPLE CONTROL EQUIPMENT AND COMPARISON WITH RTUs

What makes the proposed methodology so effective is that the required new ripple signaling control equipment includes only the receivers that will be installed at the PV producers' side, which are extremely cost-effective. The transmitters at the DNO side do not require any hardware or equipment change. The only software change is the Graphical User Interface (GUI) addition to the graphical environment of the human operator of the ripple signal at the control room. This addition enables the signal pair 18-19 for line No25 and the signal pair 23-24 for line No26. On the other hand, the Remote Terminal Units (RTUs) [17], that could be used to address the same problems, constitute a much more expensive solution, both in terms of installation cost as well as in terms of maintenance and operation cost. In Table II, a comparison between the Ripple signaling and the RTU solutions is presented, including cyber-security issues.

TABLE II. Comparison between Ripple signaling and RTU solutions

Solution	Investment cost per Solar power plant (€)	Installation cost per Solar power plant (€)	MONTHLY O&M cost per Solar power plant (€)	Cybersecurity
Ripple signaling	20,00	100,00	0,00	Inherently cyber secure: Internal network, no IP assignment
RTUs	1.000,00-1.500,00	100,00	10,00 (for internet)	Vulnerable to IoT threats

VI. Conclusions

Due to large amounts of DGs connected lately to the LV and MV network, some parameters of the grid can't be measured accurately, and many load transfer operations are prohibited due to thermal capability or to voltage values. With the help of the ripple control system, we can control the operation of the DGs. The solution involves already known systems, low cost intervention, and legal compatibility. It is inherently cyber secure, since the signal transmission involves the distribution network only, and no broadcasting on the internet takes place. Comparing to the RTU solution, the ripple signaling is much more effective, especially in terms of investment and O&M cost and of course much more cyber secure and data-privacy protective. The simulation results are absolutely encouraging: With ripple signaling control, the voltage level of every node of the MV network is below the limit of 22 kVs, which is not the case without applying ripple signaling, especially at distant nodes from the substations.

VII. ACKNOWLEDGEMENTS

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