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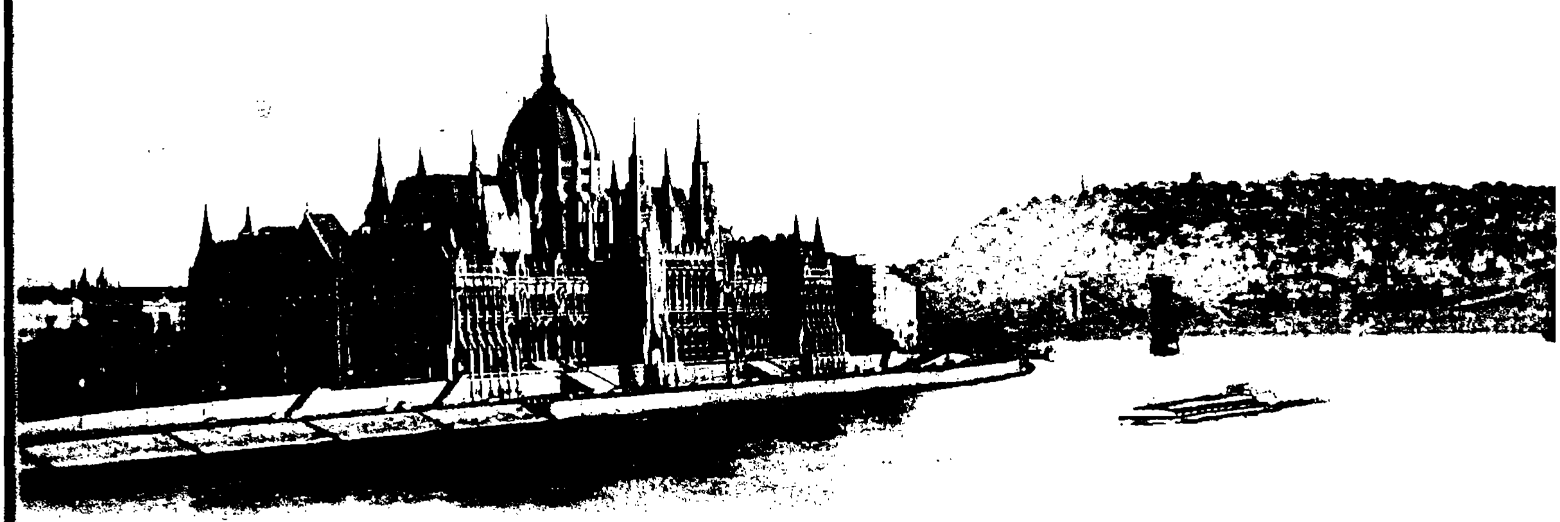

Status quo of Distributed Generation, future trends and recommendations for active Distribution Grid Operation in Austria

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Abstract. While distributed generation (DG) from renewable energy resources is seen as a key element of future energy supply, current electricity grids are not designed to integrate a steadily increasing share of distributed generators. In order to avoid excessively expensive grid reinforcements, new solutions for active grid operation have to be found. Therefore, this paper introduces new promising and innovative technical solutions for active distribution grid operation combined with tailor made communication infrastructure designs. These IT-solutions evaluated (radio links and fibre optic) demonstrate in a first stage the technical and economical feasibility for a specific DG grid integration case study, which is prepared within an ongoing Austrian research project. The lessons learnt show that the high security and reliability standards set by the distribution grid operators significantly reduce the quantity of available communication options and therefore boost resulting cost to their upper limits.

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Keywords

Distributed Generation, active grid management, innovative communication infrastructure, recommendations for DG based IT-solutions

1. Introduction

The observed rapid deployment of Distributed Generation (DG) in recent years and the present uncertainties concerning adequate grid integration methodologies are closely linked to technical feasibility and new communication solutions. The traditional power system designed for unidirectional power flows can not handle the high penetration of DG that is needed to reduce the usage of conventional power plants based on fossil or nuclear primary energy. To avoid overvoltage problems resulting from reverse power flows that are caused by generators distributed over the grid, new innovative solutions compared to expensive grid reinforcements have to be found. Although a well-balanced special distribution of loads and generators can potentially solve this problem, the grid location of new generators cannot be arbitrarily chosen. While strong urban grid segments might still have capacities to incorporate more DG units, some grid segments in rural areas are already reaching their limits. Future deployment of DG will increasingly depend on the design of innovative distribution grid operation and its corresponding cost compared to the cost of traditional grid reinforcements. Therefore, coordination of and communication with DG units can offer a key solution to power quality issues caused by increasingly high DG densities.

The Austrian research project DG DemoNet-Concept is evaluating technical measures to allow higher DG densities in the distribution grid. It is found that in order to avoid expensive grid reinforcements a (currently non-existing) real-time information flow between grid generators and also loads has to be implemented. The approach followed within the project is to gain and make use of possible influences on certain variable grid components such as generators, selected loads and also on-load tap-changer transformers (OLTC). By utilising the flexibilities offered by these components, the grid can actively be controlled and the grid voltage at every node can be kept within the prescribed limits. Since the active grid elements are spatially distributed, remote control and remote metering in real-time is essential for the effective and safe operation of the system. The design of an extended communication infrastructure in the distribution grid is subject to the tradeoffs between reliability and costs. In this paper, grid investment options and running costs for different solutions in terms of communication and grid control policy are evaluated and economically rated.

2. Methodology

As mentioned above, the economic and technical assessment is carried out in a case study. Due to the individuality of grid segments it was found that no ‘typical’ distribution grid structure for Austria (and even for other countries) can be specified. Hence, it was decided for the DG DemoNet project to concentrate on three different real examples from three different distribution network operators (DNOs), so that as many as possible grid specifics are covered. In this paper, one of these grid segments is discussed on exemplary level. This exemplary grid segment which was selected for detailed analysis with respect to possible technical- and IT-solutions as well as economical issues [1, 2, 3] is shown in Fig. 1. This network comprises about 200 nodes and represents a total demand of 9 MW_{el}.

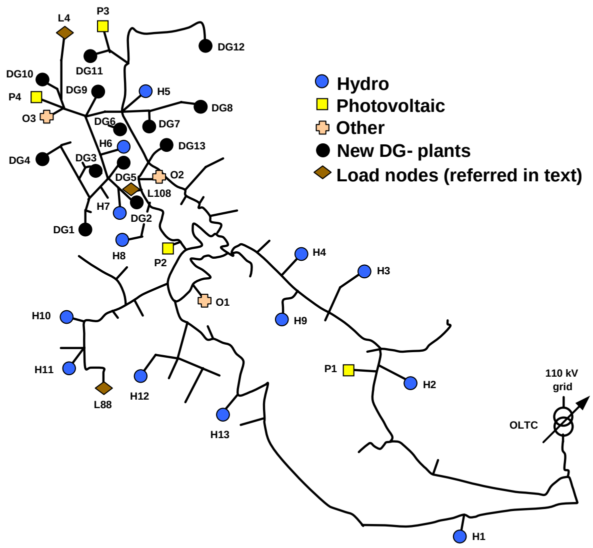

Fig. 1 Exemplary grid structure within an Austrian distribution grid

3. Techniques for voltage control

Keeping the voltage between prescribed [4] limits is becoming a primary concern of DNOs. Increasing level of DG penetration causes the voltage to rise above limits, presenting risks for customer equipment. As the present DNO’s voltage control equipment is only able to handle limited amount of DG, the upgrading, replacement and new installation of different assets is necessary to increase the DG penetration on the distribution networks. Loads, line impedances, power exported by the DG and the distance of the DG from the primary substation are the most important factors causing the changes in the voltage profile.

In the course of the DG DemoNet-Concept project, a set of new approaches for voltage control in grid segments with a high penetration of DG has been developed. These tools actively use network assets (e.g. OLTC transformers), distributed generators and even loads to perform voltage control. These tools have been implemented into a simulation environment for validation and improvement. For this purpose, the simulation software DIgSILENT PowerFactory® has been used and adapted to allow performing realistic simulations. Validations have been made on exemplary MV networks provided by DNO participating in the project, of which the one discussed in this paper is shown in Fig. 1. Realistic and worst-case profiles for representative weeks in the year have been used for modelling the generation and load behaviour in the grid segment. A number of different scenarios have been simulated. The main scenarios are listed in Table I. They differ in the amount of additional DG units that have been assumed to be present at realistic locations in the example grid, and the techniques that have been used to keep the voltage within the limits. The table also shows whether simulation results proved the selected control techniques to be successful in this particular example network or not.

TABLE I
SCENARIOS OF DIFFERENT DG PENETRATIONS AND ACCORDING CONTROL APPROACHES EXAMINED FOR THE EXAMPLE GRID

DG penetration	Local voltage control	Distributed Voltage control	Coordinated Voltage Control
+50 % of maximum load in grid segment	successful	successful	successful
+100 % of maximum load in grid segment	still voltage problems	still voltage problems	successful
+150 % of maximum load in grid segment	still voltage problems	still voltage problems	successful

The considered techniques are subsequently described:

A. Current practise

This first step (not shown in Table I) corresponds to the current approach, i.e. passive network operation. In case of voltage limit violation due to the connection of DG, the network must be reinforced, also to avoid an automatic disconnection of the DG units caused by overvoltage.

B. Local voltage control

In this approach, the OLTC is further controlled traditionally (fixed voltage set-point), but some selected generators and/or loads perform local voltage control with reactive and active power management.

C. Distributed voltage control

In this step, the OLTC is controlled according to real-time voltage measurements at *critical nodes* of the network. Critical nodes in the network present the location where either maximum or minimum voltage may occur under various network load and generation conditions. In case the voltage exceeds the operational limits at one of the monitored nodes, the OLTC performs a tap change. The effectiveness of this control is limited by the network characteristic (e.g. different load flow characteristic of medium voltage branches). This solution requires a communication infrastructure with limited requirements (unidirectional data flow) between selected nodes and the OLTC controller.

D. Coordinated voltage control

This step represents the most complex control (coordinated use of measures in B and C) strategy. A control unit controls the OLTC and the generators and/or loads participating in local control on the basis of the measurements received for the critical nodes. The use of coordinated local control allows solving the conflict appearing in the previous approach (OLTC not able to maintain the voltage within the limits in the whole network). Like in the previous steps, the critical nodes and the controlled generators have to be suitably selected. For this control, the requirements on the communication infrastructure are higher (measurement data and control signals).

4. Potential solutions for the communication system

A broad range of potential communication media can be taken into account for the purpose of communicating measurement data and control commands in the system described in the previous section. The actual choice has to be made on the basis of required latency, dependability and cost restrictions.

A. Communication demand of the system

The current system design (Fig. 1) includes a number of critical nodes (8 in the example, in general not more than approx. 20) which have to provide real-time measurement data every control time step T_c (T_c is in the range of some seconds, e.g. T_c=6 s). The data is sent to the CVCU (Central Voltage Control Unit) which can be situated at the substation of the controlled grid segment. The maximum delay for the data transmission is also T_c. This is a relatively relaxed delay constraint, but for low-bandwidth links or for strongly congested links (or even the combination of both), signal propagation delays of more than T_c are possible. So, care has to be taken that the system operation is not disturbed by sporadic communication failures.

In addition to the regular transmission of measurement data to the CVCU, the CVCU issues sporadic control signals for selected generators and loads in the grid. The maximum frequency of these control signals is again one signal every T_c. period. An acknowledgement of control commands has to be sent back to the CVCU also within T_c, resulting in a maximum delay of $T_c/2$ (e.g. 3 s) for control signals and acknowledgements each.

B. Communication options

Table II shows the range of potential communication options which starts with low-cost Internet communication. Access can be realised via telephone lines or wirelessly using GSM or UTMS services. On-demand dial-up links are not possible since the system has to be ‘always-on’ due to the delay restriction. Therefore, only leased lines or wireless Internet connectivity comes into question. The wireless option is promising in terms of easy setup and relatively low costs. However, the communication specifications are only met during typical operation of the GSM or UMTS link. No guarantees for the connectivity and the delay are given, so it can be expected that in times of high congestion of the GSM or UMTS network the operation of the control system is negatively affected and can even break down completely. Further, the Internet option raises a number of concerns regarding safety and security since network assets factually would go ‘on-line’ and therefore would potentially become accessible for unauthorised intruders. Furthermore, connectivity cannot be guaranteed. Nevertheless, for controlling small generators, which are not essential for the correct operation of the control system, this might be the only economically feasible solution.

To avoid the usage of a public infrastructure and the dependency to an external provider, DNO-owned communication infrastructure can be set up. However, this is usually linked with high investments in setting up the infrastructure. These investments possibly can be held low if existing infrastructure is re-used.

TABLE II
OVERVIEW OF POTENTIAL SOLUTIONS FOR COMMUNICATION INFRASTRUCTURE

Option	Advantages	Drawbacks
Modem dialup	▪ Easy to set up ▪ Medium costs	▪ Not always on (or high costs) ▪ Long connection times ▪ Dependency to external provider
GSM/UMTS	▪ Always on ▪ Easy to set up ▪ Low costs	▪ Not highly reliable ▪ Dependency to external provider ▪ Security issues due to Internet connectivity
Distribution line carrier	▪ Owned by DSO ▪ Medium costs	▪ Difficult to realise if many transformers are in the link ▪ Radio interference possible
Radio link	▪ Easy to set up ▪ Owned by DSO ▪ Medium costs	▪ Restricted range ▪ Depending on geographical setting
Optic fibre	▪ Very reliable ▪ High bandwidth ▪ Low delay ▪ Owned by DSO	▪ Difficult to set up ▪ Very high costs

This is the case for communication over distribution line (DLC), where the actual media already exists and additional installations are only necessary to couple the communication signal into the distribution line and to bridge cut-off points, transformers etc. As long the number of points that need DLC signal bridges is not too high in the grid segment, DLC is a feasible communication solution for the application discussed here.

Another communication option, where the media is already existent, is the use of radio links. Again, the system is DNO-owned, and investments in end-point equipment are relatively low. In terms of bandwidth, adequate solutions exist. The delay is strongly dependent on the topology and resulting routing strategy in the network. In general, radio links are feasible where the communication partners (generators, loads, critical nodes on one side) are in a line of sight to the CVCU and distances are not too high. Repeaters can be set up if this is not the case, but each repeater increases the costs and the routing delay.

On high end of the price range for potential communication media is the establishment of a DNO-owned fibre network reaching all grid assets that take part in the control system. The backbones of such fibre infrastructure exist already in some grids, but currently they reach only large assets like transformer stations on the medium voltage levels. Individual DG units or even loads are currently not connected. This dedicated grid operation control network offers optimal security and transmission conditions; however, it is a very costly solution.

The actual solution can only be a heterogeneous system, with carefully selected components, integrating different communication media and various transport protocols for economic reasons. Extending the Infrastructure toward load management can also be considered. This will allow an integral information network that allows for efficiency optimisation by actively including all ‘players’ in the distribution grid [5].

C. Remaining choices

Considering the number of previously discussed solutions, which differ in costs and applicability in different situations, the actual choice of the communication technology can become a non-trivial task. A general optimisation approach for this kind of problem and application is discussed in [6]. However, experiences made in the DG DemoNet-Concept project show that in practice strong side-constraints exist, that rule out a number of options and therefore restrict the number of choices to a small number. In this case, any solution depending on an external service provider was regarded as not dependable enough. Especially any Internet-based communication was ruled out due to security concerns.

Further, the DLC option is not always feasible for grid segments that have a distinct oblong structure (e.g. mountain valleys) with a number of interfering assets such as transformer stations, cut-off points etc. in the line. Finally, in certain geographic situations, direct radio links are not always possible.

From the remaining solutions, the radio links option and the fibre optic solution shall be considered in this paper, the first as a representative for the group of medium investment solutions, the second as the ultimate solution for current and future communication needs.

5. Economic Results

As mentioned in chapter 4 the radio link and fibre optic communication solution has been chosen for transferring the signals needed in order to implement active grid management (DG units in size of a 150% of the maximum network demand were integrated for this case). In Fig. 2 the methodology of connecting measurement units to the CVCU by radio link can be seen, which results in an overall share of ~22% for IT-installation cost compared to the total cost (~950.000 €) for the active grid solution. As a matter of fact it was assumed that direct radio links can be established for each measurement unit properly and no disturbing interferences occur. The fixed cost were stated at 4.000 € per communication unit resulting in 100 € running cost per year due to licence fees. On the whole, this communication design meets the security and reliability standards of the DNO's at satisfactory level in the simulation.

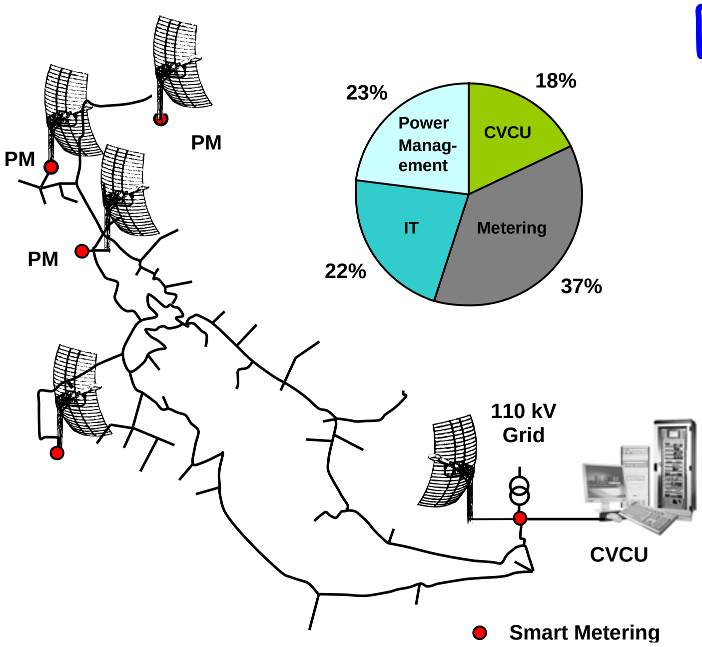

Fig. 2 *Outline of necessary radio link connections (8 in total within the exemplary grid simulation), power management (PM); CVCU and smart metering installations as well as their corresponding investment shares within the chosen Austrian distribution grid, in order to integrate a 150% of DG*

Alternatively to the radio link solution, Fig. 3 shows necessary installations in the exemplary grid, if the needed signals are transferred via optical fibre. For this, the DNOs reported cost of approximately 16.000 € per km optical fibre including all installation cost. This cost scenario can be seen as worst case, because it is assumed that there exist no communication assets in the network and therefore all cables have to be laid where necessary. As a result, the share of IT-installation cost increases drastically to 70% (overall cost ~ 2.2 million €), which possibly will be too high for a future demonstration project. On contrary, the fibre optic solution meets the needs of the DNOs most satisfyingly.

In General, the question arises who will pay the occurring extra cost for active grid management and communication installations within such distribution grids. The current grid connection approach in Austria charges all incurred grid cost to the plant operator.

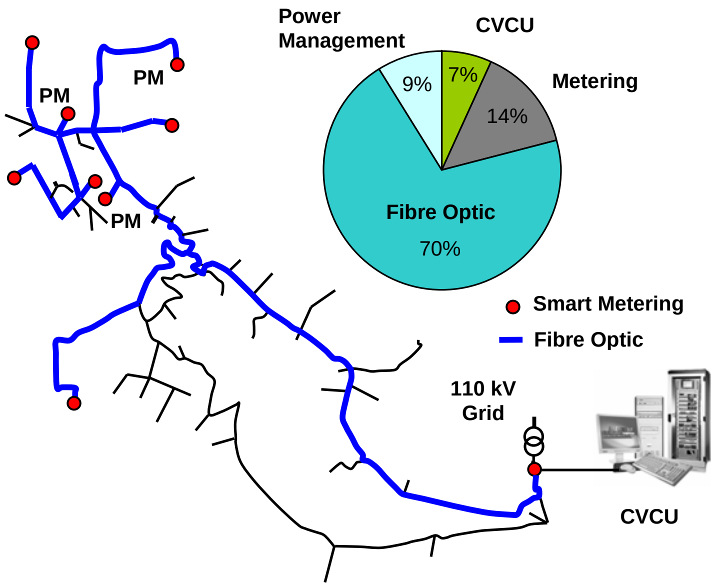

Fig. 3 *Outline of necessary fibre optic connections (~ 36 km in total within the exemplary grid simulation) and corresponding investment shares within the chosen Austrian distribution grid, in order to integrate a 150% of DG (see also Table I)*

In order to find new and innovative grid integration solutions the cost for active grid management systems must not be higher than cost for conventional grid reinforcements. Creating incentives for plant operators to participate within a demonstration project would therefore mean to reach even lower cost. This is why, some open questions and overall cost for projected communication solutions (within the case study) are presented in Table III.

TABLE III
OVERVIEW ON COST FOR CHOSEN COMMUNICATION INFRASTRUCTURE OPTIONS

Option	Overall cost within example grid	Open questions
Radio link	▪ 210.000 €	▪ Are all communication partners in a line of sight to the CVCU? ▪ Can all possible communication failures be eliminated?
Optic fibre	▪ 1.730.000 €	▪ Is it possible to integrate fibre optic solutions in a demonstration project? ▪ Who should pay such cost for active grid connection in the future?

To sum up, the core question that arises within the project is the question of cost allocation. Fig. 4 and Fig. 5 therefore show that cost for active grid management decrease drastically if DG penetrations increase. A similar tendency can be expected over time due to learning effects [7].

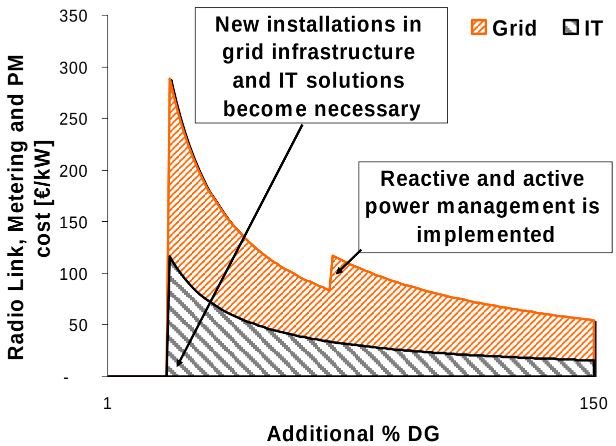

Fig. 4 *Cost shares of radio link, metering and power management installations in the exemplary distribution grid case study; the penetration of DG units within the grid is varied from 1 to 150% of the maximum network demand (see also Table I)*

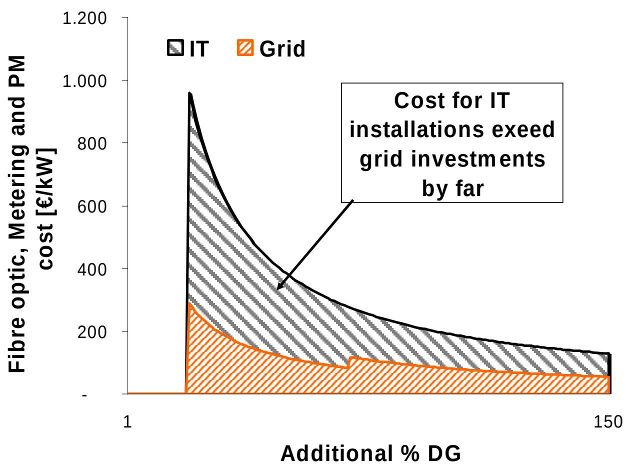

Fig. 5 *Cost shares of optical fibre, metering and power management installations in the exemplary distribution grid case study; the penetration of DG units within the grid is varied from 1 to 150% of the maximum network demand (see also Table I)*

It has to be mentioned, that an increase of 150% of DG penetration and the corresponding investment needs have to be seen as a first simulation result for only one particular case study. Therefore, the next steps in the project will concentrate on the identification of potential new DG plants and existing communication infrastructure in three selected demonstration regions in order to minimize overall cost for active grid management and to collect comparable data.

6. Conclusions

It can be seen, that the simulations performed, the control algorithm implemented and the communication options chosen work very well for the particular case study. Further steps in the ongoing project will show if these technical approaches can be easily adapted to other distribution grids in Austria.

On contrary to that, it will be of major importance to design sustainable active grid solutions for both, grid operators and plant owners. In fact, lessons learnt show that the high security and reliability standards set by the distribution grid operators significantly reduce the quantity of available communication options and therefore boost resulting cost to their upper limits. As a result, the possibility of combining existing communication infrastructure and new IT-installations has to be evaluated in further project steps in order to identify minimum overall cost.

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