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Werner Spiegel, Rolf Hamann

Disruption PowerRoad 2.0 –

Paving the way to the future of national grid expansion by bundling electrical grid infrastructure with federal highways

Introduction and evaluation of the initial situation

The fact is, there is a lack of demand-driven, approvable power lines for the high-voltage grid expansion that is required. The imperative to bundle different infrastructures is anchored in the German Federal Nature Conservation Act and the Regional Planning Act, which states that new power supply lines should, if possible, be built along existing line infrastructure such as railway lines, canals or motorways or next to existing power lines.

The 2021 amendment to the federal requirement plan is an attempt to counteract the dramatic delay to the expansion of the energy grid, with the absolutely reasonable aim of significantly accelerating it.

In the current ProgRess III programme,[1] the German federal government draws attention to the fact that it intends to further develop and implement bundling concepts for infrastructure.

Accompanying amendments to the Energy Industry Act (e.g. Section 12 EnWG), according to which the “necessity on behalf of the energy sector and urgent need” for power line construction projects is stated, as well as extensive amendments to the Grid Expansion Acceleration Act (NABEG) indicate that the causes for delays in grid expansion are unfortunately attributable to the previous approval procedures only, whereas the hoped-for acceleration of grid expansion through the option of underground cabling (since 2015) has not been achieved to date.

Instead, more than five years of “hope” have gone by, and the pressure on politicians, the Federal Network Agency and the network operators (TSOs and DSOs) has increased to finally come up with innovative solutions that are not just driven by fear and limited to increasing pressure on affected municipalities, citizens, farmers and foresters by declaring an “emergency situation for the energy transition”, so often used to justify abridging legal processes and legally anchored enforcement measures.

Without taking the **causes of the decreasing ability to reach consensus** and acceptance of the necessary grid expansion seriously, the grid expansion, the bottleneck of the energy transition in Germany, will continue to fall short of

[1] German Bundestag, 19th electoral term, printed paper 19/20375 of 18.06.2020, information by the German federal government: Programme for the sustainable use and conservation of natural resources, 2020 to 2023 (German Resource Efficiency Programme III)

expectations. Even incentive systems, such as increased compensation payments for the loss of value of land and areas used for agriculture and forestry, will not be sufficient to significantly change the situation.

The massive opposition from those affected, who already describe themselves as the losers of the energy transition, is directed in a reasonable manner against the planned grid expansion and comprises the following key points:

- Landscape conservation
- Environmental protection and soil conservation
- New consumption of resources (land and surface area)
- Conflict with legal claims of affected landowners and citizens
- Long-term threat to the livelihood of agricultural and forestry business
- Low adaptability (flexibility) of the grids for future demand
- Increasing electricity costs for end consumers (private households and economy) due to delayed grid expansion, e.g. due to high consequential redispatch costs, etc.

Just a few years ago, when transmission and distribution grid expansion was planned exclusively on the basis of overhead power line technology, landscape conservation finally led to the switch from overhead lines being regarded as given to prioritising underground cable technology for the planned new HVDC transmission lines in Germany.

After completion of the national requirements planning phase for the new HVDC electricity highways in accordance with NABEG and the findings from it, the currently planned grid expansion, in accordance with the Grid Development Plan 2035 (2021) and in the basic understanding of the amendment to the Federal Requirements Plan Act (2021), still has the main objective of accelerating grid expansion, with even greater socio-political relevance and explosiveness than ever before.

Meanwhile there is a comprehension that future grid expansion must increasingly ensure more consensus between the respective stakeholders, regarding ecological compatibility means sustainable use and conservation of natural resources and long-term affordability just starting from the planning process. The **AGS PowerRoad 2.0 concept** aims to meet this multiple demand and more.

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Finally implementing the bundling requirement with PowerRoad 2.0

A **paradigm shift** is needed, without which, in our opinion, the hoped-for acceleration of grid expansion cannot succeed. However, a paradigm shift is only justified if the required market-ready technology is available. To this end, it is crucial to first be able to demonstrably fulfil all technical prerequisites for the implementation of the PowerRoad bundling concept – an indispensable foundation for a strategic reorientation of grid expansion planning.

The implementation of the PowerRoad concept must be preceded by political action, which can be backed up by an amendment of the framework legislation for grid expansion, before a strategic investment worth billions of euros is made in the **empty line pipe infrastructure**, **which in the context of the PowerRoad implementation must be understood as an integral part of the existing basic road infrastructure**. Establishing this fundamental understanding is a challenge, since it presupposes the unification of two worlds that have hitherto been separate: transport networks (highways) and energy grids. With the PowerRoad concept, for a long time AGS has consistently adopted the insight, supported by science, society and politics, that the energy transition can only be successfully implemented in connection with a mobility transition and a thermal energy transition. To achieve this, market-ready technology had to be developed which could also be universally deployed and, particularly important in our opinion, could easily be installed by construction and installation companies using state-of-the-art technologies.

The familiar AGS technology has been further developed in a targeted manner to fulfil three essential boundary conditions and requirements for the PowerRoad concept.

1. Innovative construction and installation technology for cable laying and replacement

The AGS cable-laying technique, known as buoyancy-supported slipping, has been tested with regard to construction and installation many times at the Stade site since 2016 and has already been described, among other places, in the annual issue of *Anlagentechnik* from 2020.[2]

[2] Hamann, Rolf, Spiegel, Werner, AGS-Erdkabelsysteme – mehr Planungssicherheit durch marktreife Technik zur Förderung der Konsensfähigkeit, Umweltverträglichkeit und Wirtschaftlichkeit zukunftsfähiger Stromnetze, in: Cichowsky, Rolf Rüdiger (ed.), *Anlagentechnik für elektrische Verteilnetze*, Yearbook 2020, VDE-Verlag, Berlin, Offenbach 2021, p. 209ff

AGS-Verfahrenstechnik GmbH
www.ags-verfahrenstechnik.de

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ZERTIFIKAT

Registrier-Nr. 20180830

zum Erdkabelmontageverfahren der
AGS-Verfahrenstechnik GmbH

Auftrieb-Gestütztes-Slipping-Verfahren
(AGS-Verfahren)
zur Verlegung von Höchstspannungskabeln

wird hiermit bescheinigt,

a) dass die Prozesse zur Realisierung der AGS-verfahrensspezifischen Bau- und Montagedienstleistungen für den Standort Stade nachweislich sorgfältig geplant und systematisch ausgeführt wurden und

b) dass die AGS-Kabelverlegetechnik (nach dem Test- und Pilotbetrieb) mit den vorhandenen technischen wie organisatorischen Mitteln der Betreiber auch bei anderen Erdkabelprojekten eingesetzt und an anderen Projektstandorten analog umgesetzt werden kann

Der Nachweis wurde einerseits erbracht durch eine FMEA-Betrachtung hinsichtlich

der Zuverlässigkeit des Verfahrens.

Andererseits wurde die Vollständigkeit und Schlüssigkeit überprüft hinsichtlich der

Arbeitssicherheit.

Der Auditbericht vom 13.08.2018 ist Bestandteil dieses Zertifikates

TÜV Saarland
Bildung + Consulting GmbH
i.A.
Wolfgang Schwinn

TÜV Saarland
Bildung + Consulting GmbH
Fachbereich Elektrotechnik
i.V.
Peter Mohrbacher

TÜV Saarland Bildung + Consulting GmbH, Am TÜV 1, 66280 Sulzbach, Telefon 0 68 97 / 5 06 - 5 15

Fig. 1: AGS test operation at the Stade test and pilot site ©

In the AGS process, a so-called cable-carrier pipe system is inserted into a water-filled duct (see Fig. 1), with the condition buoyancy ≈ weight being met. In the state of "weightlessness", the frictional forces between the cable-carrier pipe and the duct during installation are virtually zero in straight-line sections (see Fig. 2).

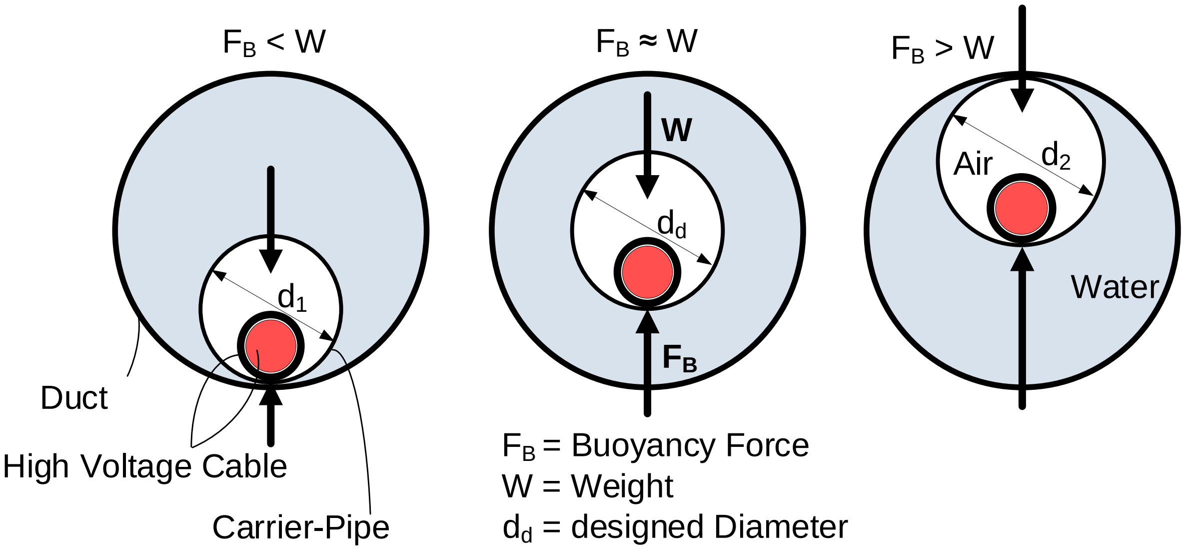

Fig. 2: AGS cable-laying technology leveraging the Archimedes' principle ©

Minor frictional forces between the cable-carrier pipe and the duct occur only in curved sections and are overcome by corresponding tension forces.

The assembly principle for a cable-carrier pipe and the insertion of the cable to be laid before it is fed into the duct is illustrated below (see Fig. 1.1 to 1.6).

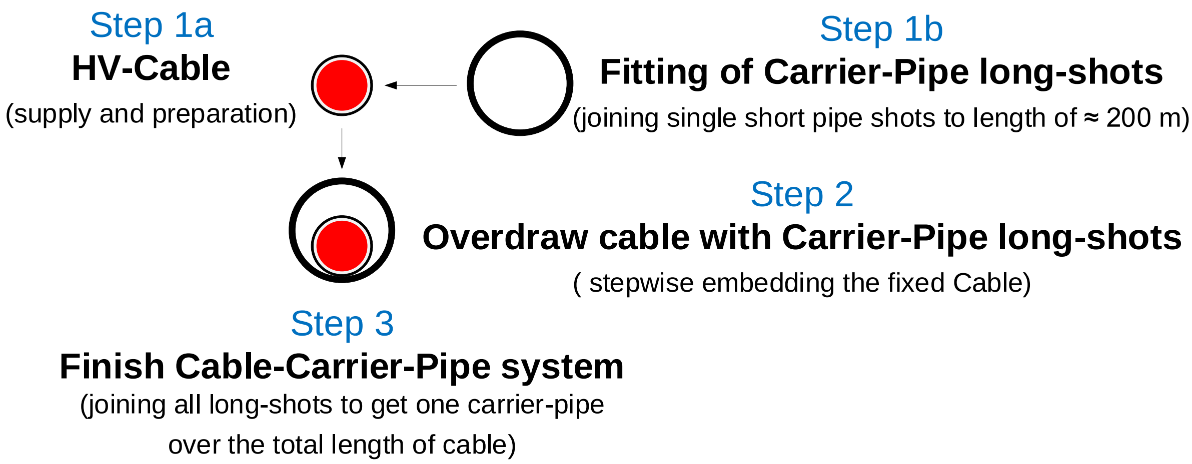

Fig. 1.1: Assembly principle: After the cable has been pulled from the cable spool onto a roller scaffold of appropriate length (step 1a), single carrier-pipe long-shots (step 1b) are piecewise pulled over the fixed cable on the roller scaffold (step 2) and connected to each other (step 3) ©

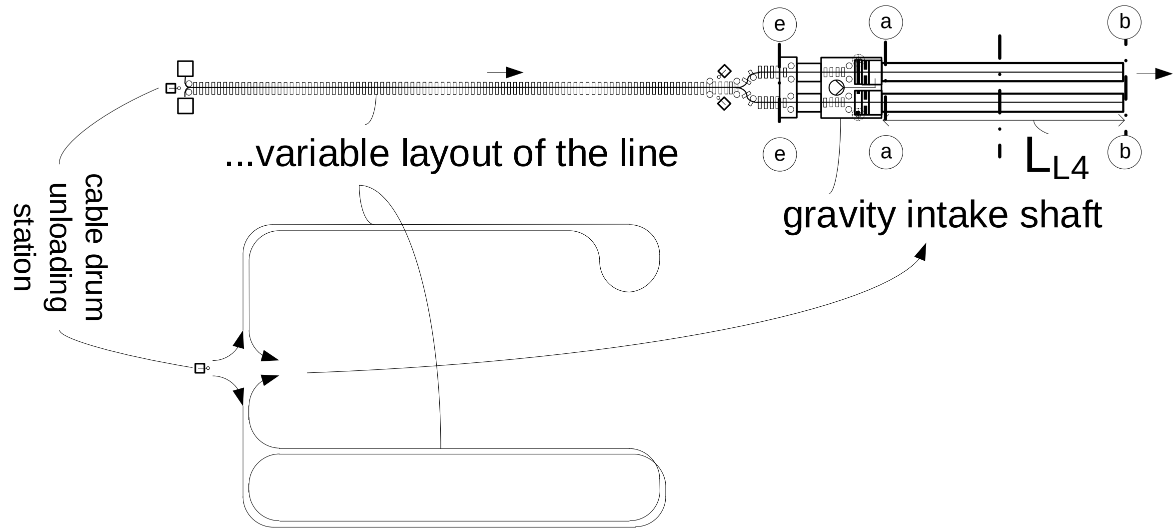

Fig. 1.2: Step 1a – Placement of the roller scaffold for longitudinal pulling between the unloading location of the cable and the gravity intake shaft ©

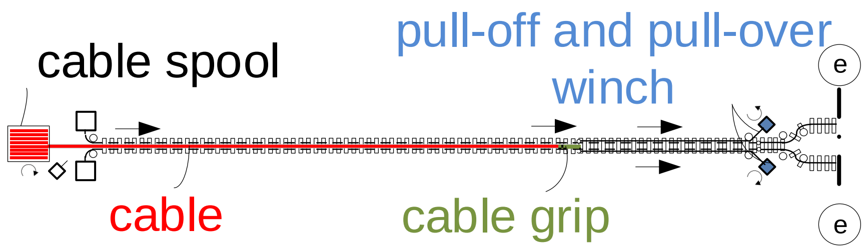

Fig. 1.3: Step 1a – Longitudinal pulling off and placement of the cable on the roller scaffold ©

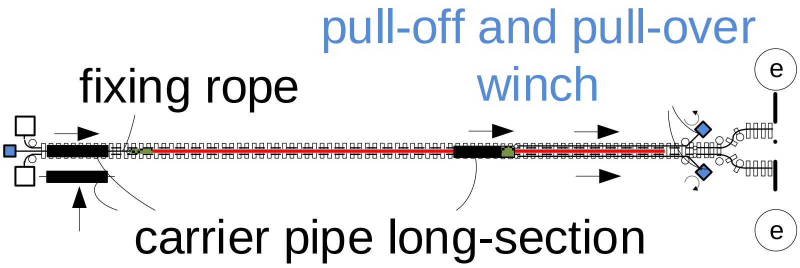

Fig. 1.4: Step 2 – Pulling carrier-pipe long-shots piecewise over the fixed cable ©

Fig. 1.5: Step 3a – Joining the cable carrier-pipe long-shots embedding the internal cable using the SIMOFUSE® process at the Stade test and pilot site

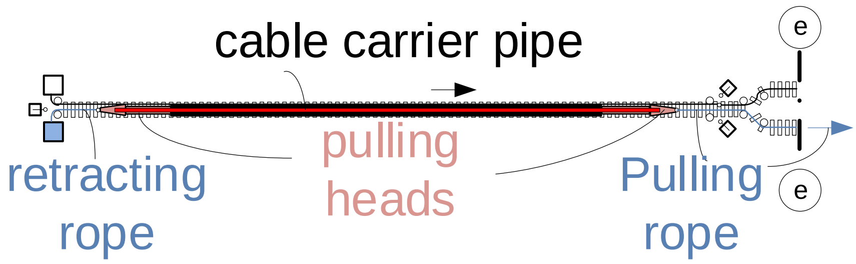

Fig. 1.6: Step 3b – Final airtight closing of the cable carrier-pipe system with removable pulling heads at both ends ©

In order to ensure sustainability for future investments, **pipe-based cable-laying technologies have to be declared the standard** and, consequently, additional flexibility criteria have to be anchored in the framework legislation, because sustainability must include flexibility that enables adaptation to future technology standards, i.e. it must be possible to later replace the installed cables without repeated underground work and without having to install ducts again.

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Construction and installation methods should therefore be able to meet quality criteria that avoid permanently and irreversibly damaging cable ducts during the initial installation, making subsequent cable replacement impossible.

Conventional cable installation (1) into ducts requires the use of so-called pushers, usually electro-mechanical cable pushers. In order to limit the tensile forces on cables, several of these pusher stations are often required, even for straight-line routes, and they must be deployed in open trenches at the time of cable installation in order to be able to install a single cable section of the entire duct route (a maximum of approx. 1,200 m of high-voltage cable can currently be transported on roads). With the conventional cable pull-in method, the damage potential and duct stress due to pulling the cable through curved, meandering routes is greatest (see Fig. 2 for comparison). External soil pressure on the duct combined with forces acting radially from the inside due to pulling the cable can damage the duct by causing permanent deformations (ovality) and indentations (rope cuts).

The consequence is that the greater the tensile forces the cable is subject to, especially in non-straight routes, the greater the probability of damage to the duct due to the interaction of vertical soil pressure and the horizontal force acting perpendicular to it inside the duct. It is likely that any damage or probable damage to the duct cannot be repaired or even detected after the cable has been installed. A later complete cable replacement can hardly be ensured with the conventional cable installation method.

In the **AGS cable installation process (2)**, intermediate pusher stations as described above are not required due to significantly lower tension forces and frictional forces. This has been shown by experience at the test site in Stade, with a meandering route about 1,100 metres long, where the damage-free reversibility of the method has been confirmed many times.

1 Conventional cable installation (Cable pulling into a duct)

2 AGS cable installation (Archimedes' principle A ≈ G)

3 AGS cable installation with additional hydrodynamic positive friction power

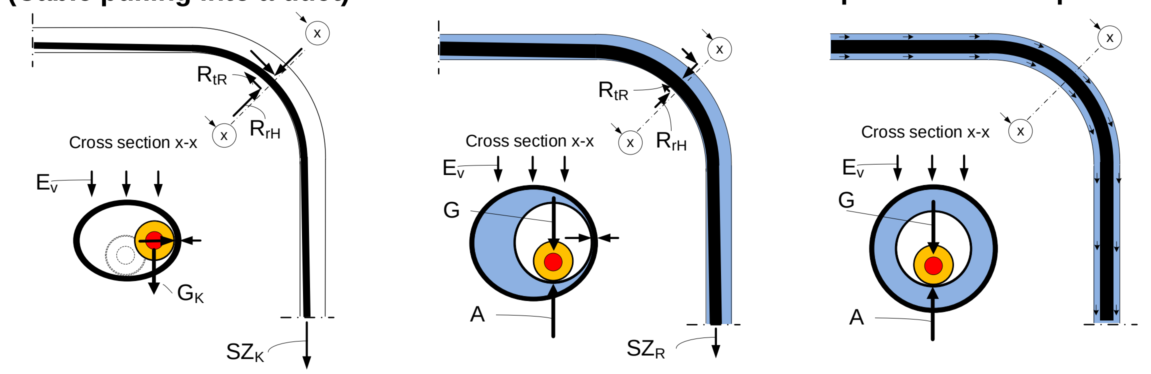

Fig. 2: Comparison of cable installation methods with regard to their potential for damaging cables and ducts ©

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With **AGS-ultra (3)**, the latest technical advancement in AGS cable-laying technology, the previous length limitations for cable installation can now be completely eliminated and the potential for damage to ducts and cables minimised. This is achieved by the simultaneous interaction of two physical effects, that of Archimedes' principle, **buoyancy** under the condition A ≈ G (see Fig. 2), **and** the effect of **positive hydrodynamic friction**, which produces a **hydro-pushing effect**. Due to this additional pushing effect on the cable carrier-pipe, cables can be installed in a friction-minimised, reversible manner even in ultra-long ducts without having to pull on the cable, especially in the case of non-straight routes (see Fig. 2 right). By means of recirculation and booster pumps (see Fig. 3 and Fig. 4) and other key hydraulic components, the necessary hydro-pushing strength can be generated, controlled and maintained for any length of time over the entire duct length, which is no longer limited in length compared with conventional cable installation methods.

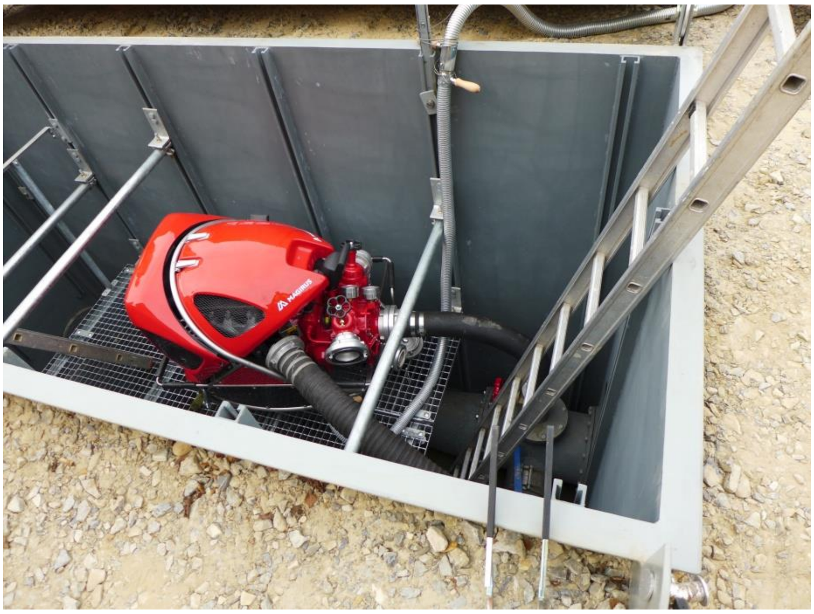

Fig. 3: AGS test operation at the Stade test and pilot site ©

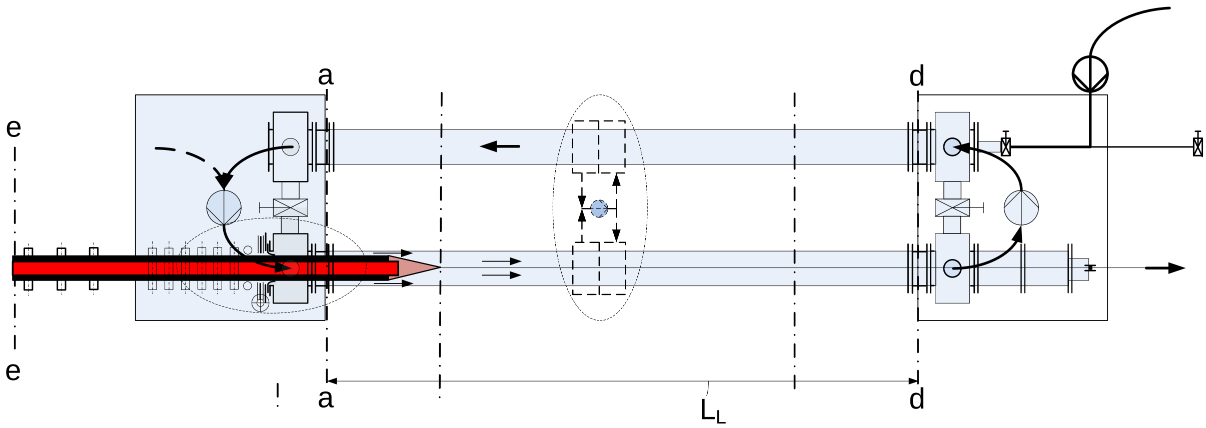

Fig. 4: Diagram – Combined AGS hydro-pushing for laying ultra-long high-voltage cables ©

By overcoming the length limitations of cable installation into ducts, efficiency and cost-effectiveness can be significantly increased compared to the AGS method already in use.

Figures 5 to 8 show schematically how multiple high-voltage cables can be installed highly efficiently one after the other into a duct system multiple times the length of a single cable for a two-phase power transmission system having an arbitrarily chosen example duct system length L_L of approx. 5 km, **using AGS-ultra from one single, remote cable unloading location**. The total system length L_L is divided into four sections L_{L1} to L_{L4} that correspond with the assumed cable length as delivered, approx. 1,200 m, and three intermediate segments L_{LM} -the later cable-joint areas- which can be opened after installation to relocate the terminal shaft and the hydraulic components for the next installation step along the route (s.Fig. 8).

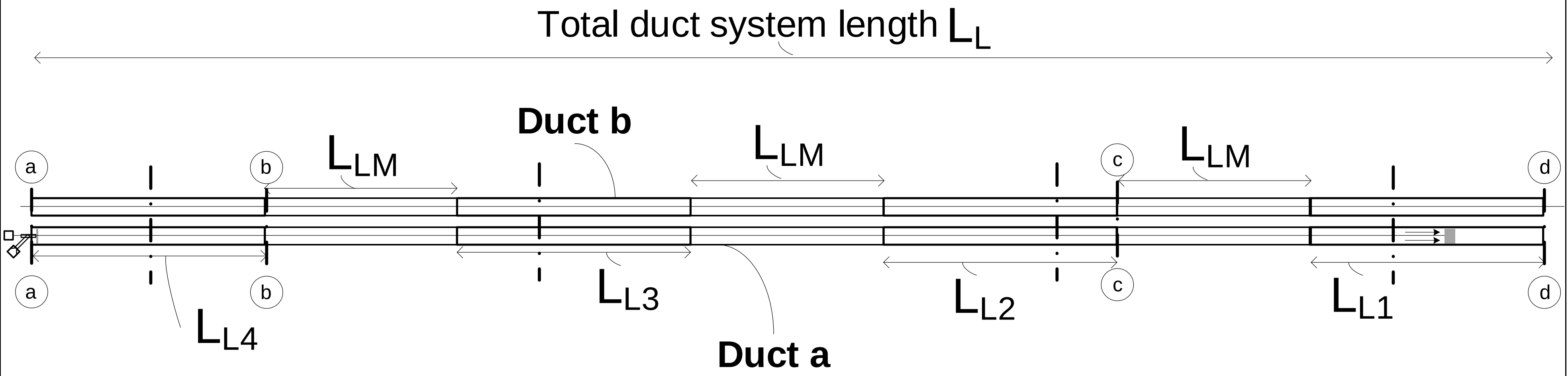

Fig. 5.1 Schematic representation of two continuous, pre-laid duct systems, with identification of the cable sections L_{L1} to L_{L4} and the intermediate sections L_{LM} -the later cable joint sections- at the time of pre-installation of the ancillary rope in duct a

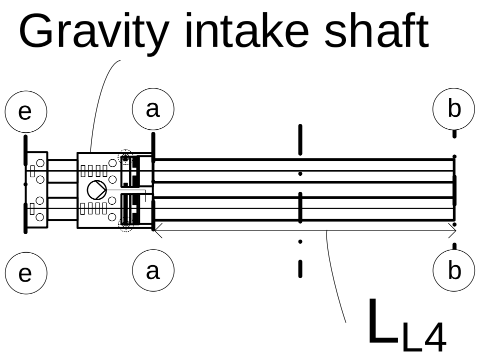

Fig. 5.2 Schematic diagram of the gravity intake shaft connection at the high-point of the duct system

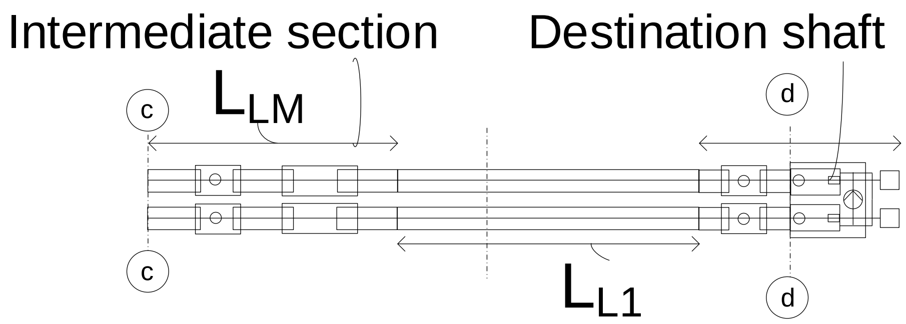

Fig. 5.3 Schematic diagram of the destination shaft, functioning as a low point pressure lock, and the intermediate section L_{LM} in preparation of the cable carrier pipe installation in section L_{L1} of duct a and b before flooding the duct system with water

Fig. 5: Pre-laid duct system in preparation of the **AGS-ultra cable-carrier-pipe installation** process ©

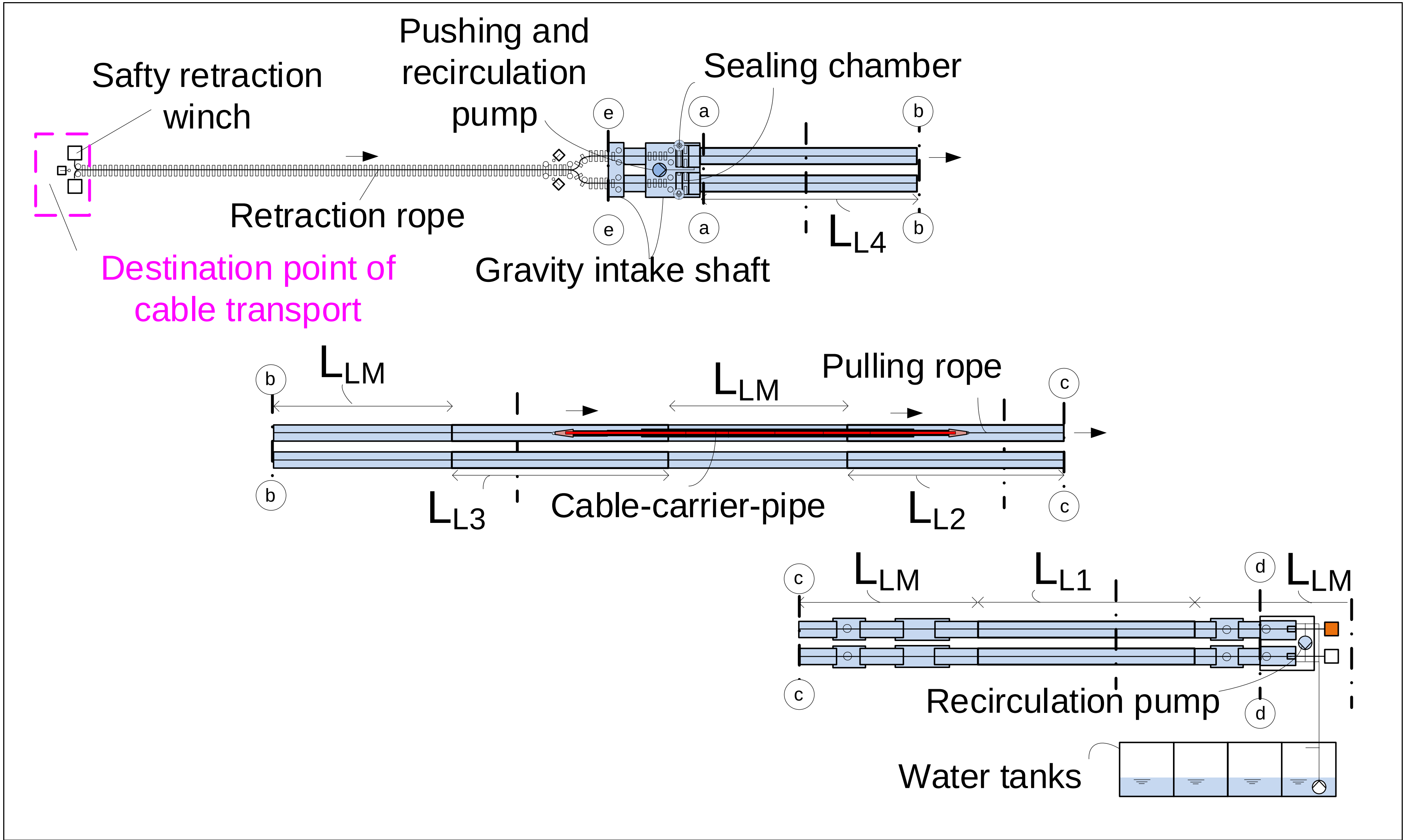

Fig. 6: Schematic diagram of **AGS-ultra cable-carrier-pipe installation in a water flooded duct system**; point in time: passage segment L_{L3} – L_{L2}©

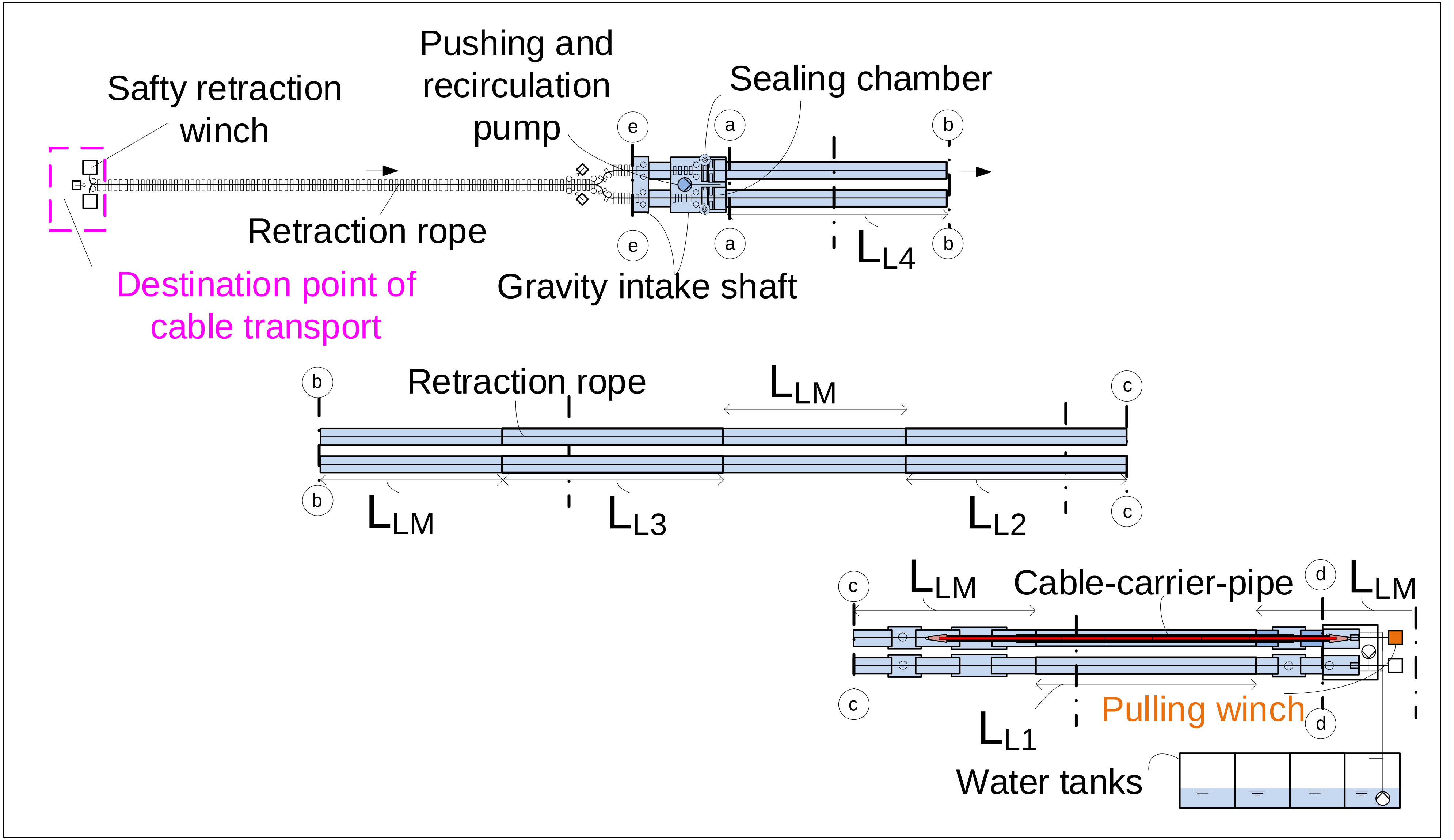

Fig. 7: Schematic diagram of **AGS-ultra cable-carrier pipe installation in a water flooded duct system**; point in time: reaching the destination segment L_{L1}©

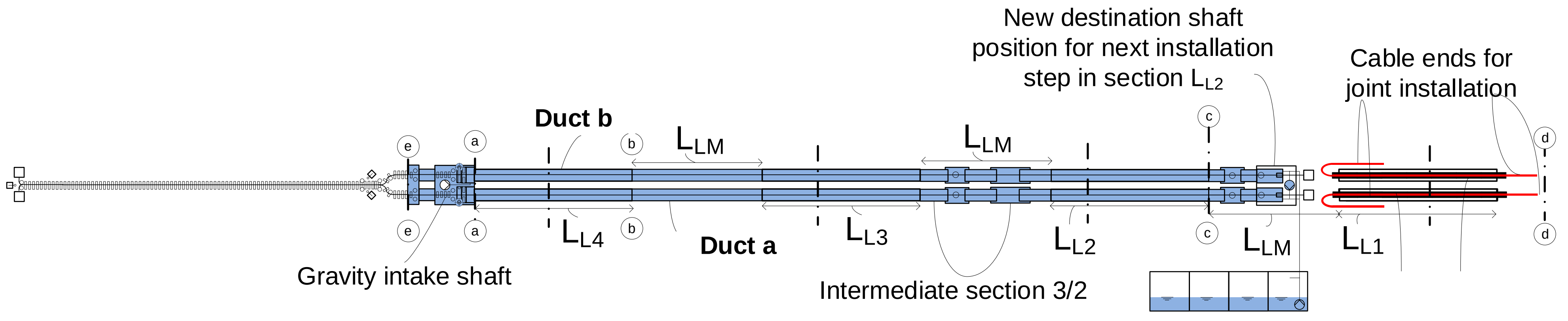

Fig. 8: Schematic diagram of **AGS-ultra cable-carrier pipe installation**; point in time: installation preparation in section L_{L2} ©

2. Compact duct installation for narrow underground power lines

The **AGS-ultra cable installation technology**, ensures on the one hand a laying process for the cables without subjecting them to tension forces (see Figs. 5 to 8). On the other hand also the **basic installation requirements for PowerRoad 2.0** can be fulfilled, making possible by **using the AGS-cable-carrier pipe method** to **install - and if necessary replace-** high-voltage power transmission systems **even and preferably underneath the roadway**.

It quickly becomes apparent, however, that such a PowerRoad concept can only be implemented if cables are laid so narrowly, e.g. in a triangular arrangement (see Fig. 9), that they can be integrated into the road structure (e.g. below the hard shoulder of motorways).

Fig. 9: Example – Narrow underground power line with triangular duct arrangement ©

In terms of construction methods, this is the state of the art and unobjectionable; see Fig. 10, which shows a typical motorway cross-section (embankment type).

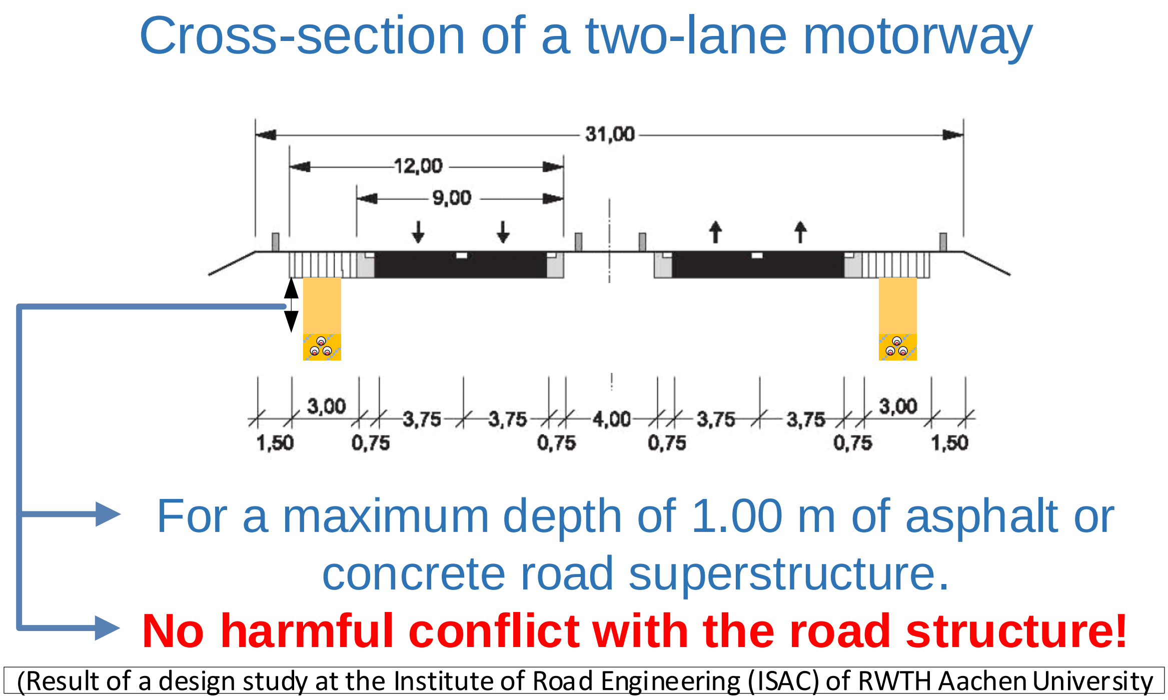

Fig. 10: Triangular arrangement of two high-voltage three-phase systems underneath the hard shoulders of motorways ©

In case of a motorway cross-section in a roadway cut where the motorway surface is at or below ground level, compact duct systems can be installed below the shoulder or along the actual structure (not shown here).

In the basic PowerRoad concept, the hydraulic-end-closures of the ducts and cable-carrier pipes as well as cable joint areas are placed next to the road structure where they are not subject to extra stress. Preferably those areas will be placed in cut-sections of the motorways.

3. Active cooling of compactly installed power transmission systems

To fully enable the PowerRoad 2.0 bundling concept, it must be possible to comply with the **operational requirements** for power transmission in narrow power lines, so that cable overheating can be reliably avoided despite compact installation.

Since 2013, AGS has been engaging in active cable cooling [3]. As with AGS-ultra, it is possible to leverage buoyancy-induced “weightlessness” and hydro-pushing to install

[3] Hamann, Rolf, Spiegel, Werner, Aktiv gekühlte Stromübertragung in Schmaltrassen, in: Netzpraxis, Jg. 54 (2015), Heft 1-2, S. 48 - 54

cable-carrier-pipes reversibly in compactly installed ducts of any length without subjecting them to tension forces, even in the case of meandering routes.

It should only be a small logical step now after using hydro-power for installation, to fill the duct/cable-carrier pipe system created in this way with tap/well water again to allow a passive or active (forced) cooling of the water bedded cables in operation [4] [5] for a safer power transmission and utilise the waste heat accordingly.

In this third and **last step – the operational implementation of the AGS PowerRoad principle –** the extraction of the waste heat from the power transmission losses can be carried out via the hydraulic-end-closures of the duct system if it is necessary to cool the system during power transmission in narrow lines. The water as the circulating cooling medium can be cooled down again as required via passing a heat exchanger, which is operated in cooling priority mode, before fed back into the duct system (see Fig. 11).

[4] e-cigré, ELECTRA 066.4: The calculation of continuous ratings for forced cooled cables
[5] e-cigré, ELECTRA 104.1: Forced cooled cables - Calculation of thermal transients and cyclic loads

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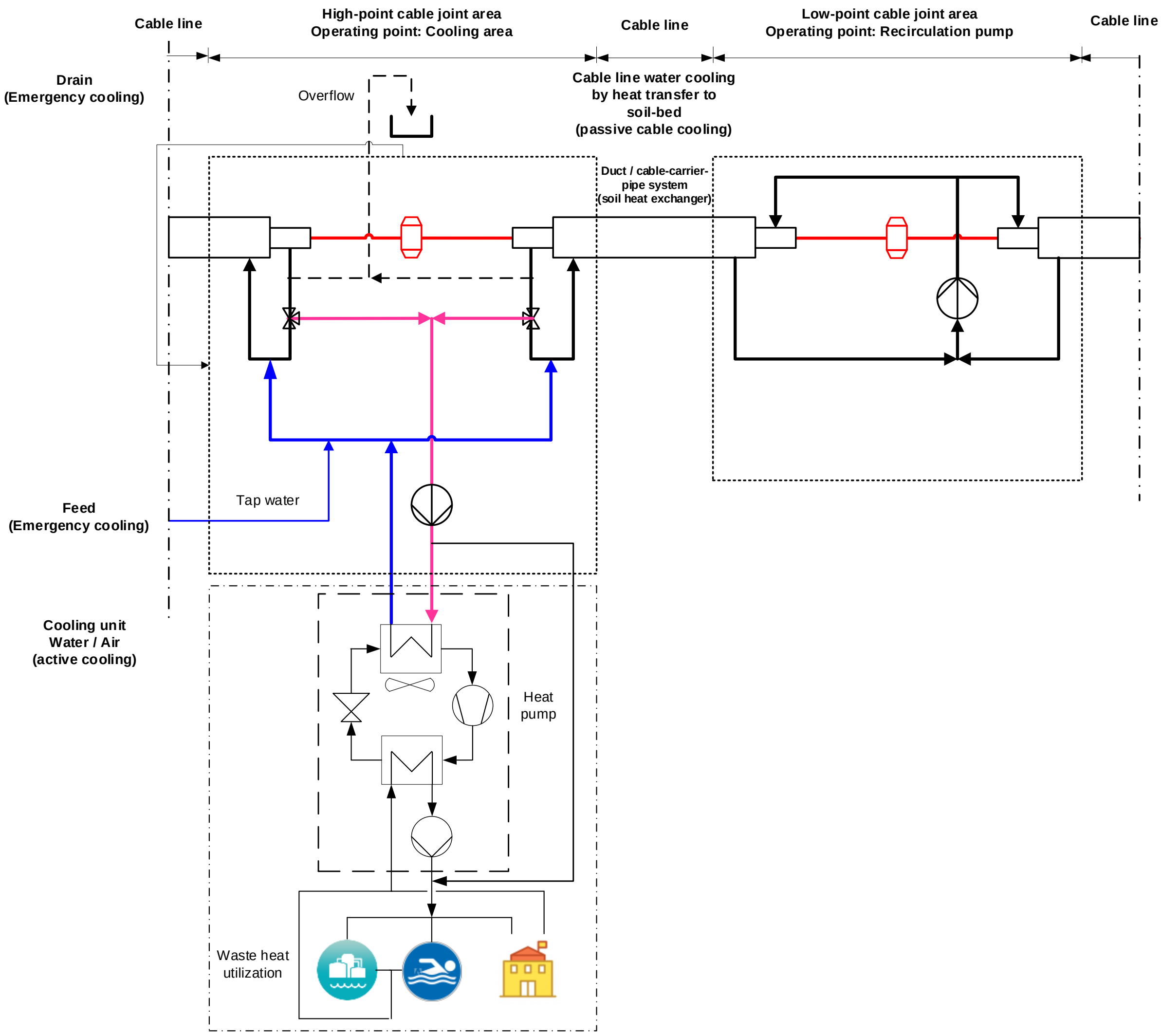

Fig. 11: Basic scheme – Passive and active cooling of AGS duct-cable-carrier-pipe system © [6]

To cool the cable-joint area (cable head and joints outside the duct), if considered independently with regard to different cooling requirements, a direct or indirect water-cooling extension can be provided (not shown here).

Conclusion and outlook

With the knowledge gained that the essential technical boundary conditions and requirements can be met, the idea of bundling high-voltage power lines with federal highways is anything but revolutionary. Quite the opposite – the innovative AGS technology, which is now ready for the market, already enables the technical implementation of PowerRoad 2.0 with regard to infrastructure bundling, a requirement

[6] Hamann, Rolf, Spiegel, Werner, AGS-Verfahrenstechnik GmbH; *Born, C., Schacht, O., Teutsch, M.*, Stadtwerke Stade GmbH: Innovative Kabelverlegetechnik und aktiv gekühlte Stromübertragung nach der AGS-Verfahrenstechnik für teilverkabelte HV-Übertragungsnetze in: Netzpraxis, Jg. 55 (2016), Heft 9, S. 44-50

that has been the legal basis for the expansion of the power grid in Germany since 2014.

In metropolitan areas, the implementation of the infrastructure bundling requirement is more than self-evident, and it has long been the state of the art here for high-voltage and medium-voltage power lines to be installed under the road. But past the borders of cities, it is not yet considered standard to install underground cables.

The realisation of compact power lines that enable transmission of large amounts of electricity concurrently without harming people, cables or the environment is a long-standing objective whose feasibility has been proven with superconducting technology, e.g. with the AmpaCity project in Essen. There, however, the start-up and maintenance of active cooling of the cables with liquid nitrogen is one of the technical challenges and hurdles that still need to be overcome.

High-voltage compact power lines with passive and active water cooling, on the other hand, as can be built and operated using AGS technology, are easy to implement with regard to economic and technical considerations. Standard components and materials and methods of plant construction ensure a water bedding of the cable in the PE-100 double pipe system (consisting of duct and cable-carrier-pipe) that protects the cable during the laying process as well as in its long-life operation.

The “revolutionary” step from land cables installed as underground cables to land cables installed as road cables therefore only has to take place in the minds of those responsible for grid planning, expansion and operation in order to make a reality what is actually the most natural and legally appropriate wish to combine electricity transmission with existing infrastructures more quickly and without lengthy approval processes. In this “only”, however, obviously lies to date the biggest constraint.