THE PATH TO HIGHLY AVAILABLE, SUSTAINABLE AND EFFICIENT OPERATION OF ROAD TUNNELS – USE OF ENERGY GENERATION AND STORAGE OPPORTUNITIES IN THE FUTURE

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ABSTRACT

The possibility of the use of industrial battery storage systems in combination with sustainable self-energy production is shown with regard to the energy efficiency of road tunnels with simultaneously improved blackout protection of critical transport infrastructures. The optimisation of energy supply and energy consumption of road tunnels is thus illuminated. Case studies of ASFINAG are described from the point of view of use cases and scenarios and road operators are given an overview of possible measures and procedures.

Keywords: Sustainability, Blackout, Critical Infrastructure

1. INTRODUCTION

Road authorities and infrastructure managers are increasingly expected to promote efficient use of energy and use sustainable methods for the construction and operation of public roads. A large part of the operating costs are accounted for by the provision and consumption of electrical energy. Especially in the field of energy-efficient and at the same time highly available operation of road tunnels, there are few guidelines and no generally accepted state of the art. If one considers that road tunnels are complex and expensive objects with a life cycle of normally more than 80 years, it becomes clear that a concept for the energy-efficient operation of road tunnels is of great importance. For this purpose, its own energy production with for example photovoltaic systems or hydropower in combination with an industrial battery storage is a possible approach. This can also lead to a significant improvement in the supply situation in the event of a power failure or blackout.

2. ROAD TUNNELS AS CRITICAL INFRASTRUCTURE

Critical infrastructures are those infrastructures (systems, facilities, networks or parts thereof) that are essential for the maintenance of essential societal functions and whose disruption or destruction would have serious consequences for the health, safety or economic and social well-being of large sections of the population or the effective functioning of government institutions. The availability of transport services and energy play a particular role in this context. [1] In the case of critical infrastructure, there are basically two sectors which link everything together and on which almost all supply services depend: Electricity and Information and Communication Technology (ICT) supply. Here, one can truly speak of lifelines, because a major disruption in these two sectors can lead to far-reaching domino effects or even chain reactions. [2] At European level, there is a programme for the protection of critical infrastructures in this respect. This programme also explicitly identifies road traffic and considers it critical in terms of its impact if it is not available. [3] This means, on the one hand, that road tunnels, as an essential part of a transport infrastructure, must have the highest possible availability and operational safety, and thus the availability of electricity is also necessary to maintain operations at a high level.

3. BLACKOUT AND POSSIBLE TRIGGERS

In the technical literature, a blackout is understood to be a sudden, supra-regional and prolonged (> 12 hours) power and infrastructure outage. In this case, other infrastructures are also affected and help from "outside" is not to be expected. Everything that is not prepared and provided for on site will not be available in this case. The triggers for a blackout can be manifold:

- Instabilities in the Europe-wide networks, voltage flashovers in overhead lines
- Uneven load distribution and the resulting overload of the power grids
- Atmospheric influences, thunderstorms, storms, freezing rain, heavy snowfall, severe cold, heat, etc. and elementary events (avalanche or debris flows, rockfalls or earthquakes) which damage the electricity grid infrastructure or cause defects
- Switching faults in substations
- Criminal and terrorist activities (sabotage, hacker attacks)

The term blackout is often erroneously used in the course of local disturbances where the power fails for a few hours and only in parts of Austria. Local disturbances due to power failures can usually be remedied relatively quickly by emergency or switchover measures. [4] In the ASFINAG risk management system, the following is defined for large-scale power failures: Supra-regional, prolonged power failure of one or more energy supply companies. This risk deals with the risk of a large-scale and long-term power failure and its effects on the monitoring and control of the motorway and expressway network. A scenario of this kind would mainly affect the electrotechnical equipment in the tunnel facilities.

4. ENERGY SUPPLY FOR ROAD TUNNELS IN AUSTRIA

In Austria, the requirements for a power supply to tunnel facilities are defined from a legal point of view in the Road Tunnel Safety Act (STSG), which is based on the minimum requirements of the EU directive on road tunnel safety. The technical implementation as state of the art is regulated in the technical guidelines for traffic-rail-road (RVS).

4.1. State of the art for energy and emergency power supply

According to the specification of the RVS 09.02.22 Tunnel equipment, the energy supply is to be provided by the electricity network. Depending on the hazard class of the tunnel equipment and the possibilities of a mains supply, these shall be adapted accordingly. This means that either a one-sided or two-sided supply of a tunnel system from the electricity network must be provided, or in exceptional cases a diesel emergency power generator may be used as a second supply. In the event of a power supply failure, it must be ensured that the entire tunnel can be fully supplied again in the shortest possible time (range of minutes).

The safety power supply equipment shall be realised by means of batteries and shall be designed for a bridging time of 1 hour 20 minutes in the dimensioning of the emergency power supply. After 10 years, there must still be at least 1 hour of bridging time. However, this means that only emergency functions are available in the tunnel and that in case of a power failure, the portal traffic lights will be switched to red and entry into the tunnel will no longer be permitted. [5]

4.2. Organisational measures and minimum operating conditions

Within the framework of the RVS 09.04.11 Maintenance and operation of tunnels, a regulation on minimum operating conditions is laid down as a guideline for possible replacement measures in cases of limited technical or traffic availability or for the total failure of installations. [6] This also deals with the scenarios of power failure and defines alternative measures in the event of a power failure. The following alternatives were identified as alternative measures for maintaining the traffic flow:

- Organisational measures are e.g.: maintain traffic despite power failure with the help of police, fire brigade, service and control service of ASFINAG, etc.
- Reduction of speed, block handling, etc.
- Technical measures: Acquisition of a large emergency power generator, so that the ventilation of the corresponding tunnel can also be operated.

The technical and organisational measures must be analysed individually due to the organisational framework conditions in case of a blackout (availability of emergency services, etc.), as well as the technical uniqueness of each tunnel taking into account the geographical location.

5. TUNNEL FACILITIES AS ENERGY SUPPLIER

Organisations such as PIARC, CEDR or COB have already developed recommendations and questions in this area and have defined energy production in the immediate vicinity of tunnels as a field of action in addition to the consistent reduction of demand. CEDR states that tunnel systems require more energy for operation during the day than at night. This is due to the higher traffic volumes and higher illuminance levels. This makes the use of photovoltaics a perfect method to cover the additional demand for electricity during the day with sustainably generated energy and thus reduce CO2 emissions at the same time. [7]

PIARC initiated the project “Positive Energy Roads (PER)” [8] and developed a recommendation. By definition, this is a road infrastructure that generates more energy than is consumed during plant operation. Ideally, the energy is provided by renewable energy production. In the report mentioned above, five levels are defined; the first two are described as follows:

<u>Level 1</u>: Percentage of energy required to operate specific equipment (e.g. tunnel lighting) that can be covered by specifically allocated renewable energy sources from own production (e.g. photovoltaic, hydroelectric power)

<u>Level 2</u>: Percentage of the annual energy requirement for the operation of road infrastructure, which is covered by renewable energy sources and own production.

The aim is to cover as high a proportion as possible of the energy required for the operation of the road infrastructure in the balance sheet through in-house energy production.

However, in order to ensure operational safety in the event of a power failure or even a longer interruption, it makes sense to consider the technical equipment of tunnel systems.

6. RENEWABLE ENERGY PRODUCTION AT ASFINAG

According to the ASFINAG Energy Audit Report 2019, approximately 142 GWh of the required final energy is accounted for by electricity as an energy source. Of this, the tunnel systems are the largest consumer group with 108 GWh. In order to be able to produce a significant proportion of the required electrical energy itself, the issue of renewable energy production has been promoted for several years.

However, the decision to construct a tunnel has so far only focused on the share of the energy generated that can be directly consumed by the users themselves and does not have to be fed back into the power grid at an unfavourable rate. Due to the existing potentials and the possible combination with powerful battery storage systems, there is also a chance of operational use in the event of a blackout or power supply failure.

6.1. Photovoltaic systems as an energy source

ASFINAG has so far equipped seven tunnel systems with photovoltaic systems, and further systems are being planned and prepared. The primary focus was on supplying the tunnel lighting, especially the adaptation lighting in the entrance area. The energy production of the photovoltaic system on an ideal photovoltaic production day clearly shows the possibilities of energy supply using the Katschberg tunnel with an installed capacity of 180 kWp as an example. During the course of the day, with good production conditions, half the energy requirement can be covered between 10 am and 5 pm with a comparatively small system. In order to achieve 100% peak coverage for normal operation, a plant of around 500 kWp would be required.

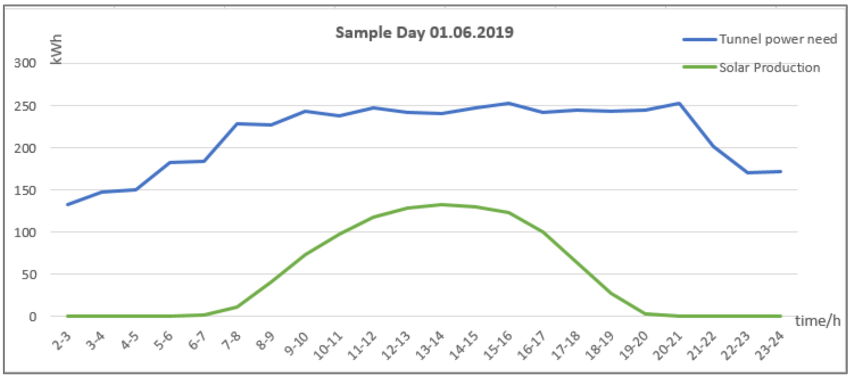

Figure 1: Sample power Graph

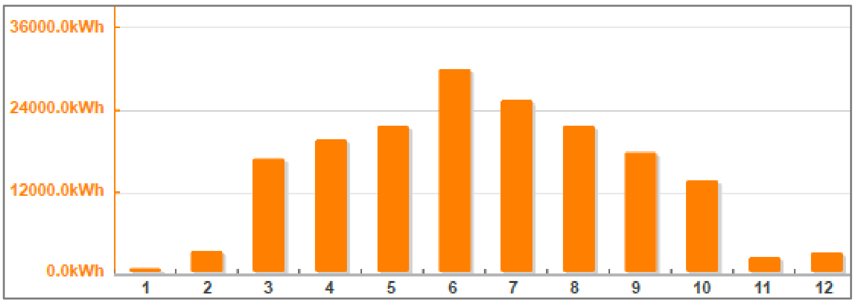

Figure 2: Katschberg Tunnel – Energy production 2019 per month

The example of the annual production rates of Katschberg tunnel unfortunately also shows the problem that hardly any energy production takes place in the months of January, February, November and December due to the weather conditions. This means that during these months, energy must be provided by an energy supply company.

6.2. Small hydropower plants

These are an interesting option provided that sufficient water is available and the rights of use are in place. However, due to water collection and transport, such plants are usually associated with high construction costs. The advantage, however, is that a constant energy level can be provided 24 hours a day via a constant water balance.

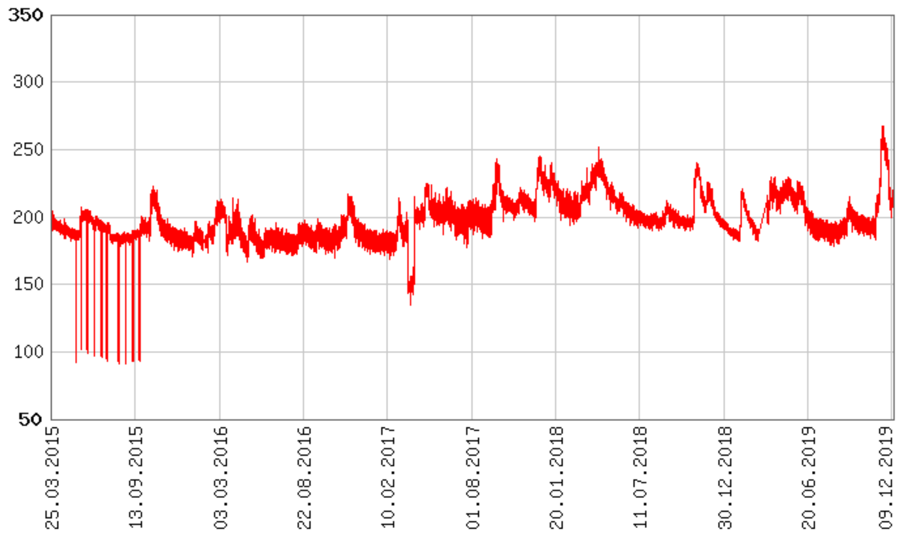

Figure 3: Karavanke Tunnel -water capacity litres/time period

ASFINAG currently has two facilities (Semmering and Karawanken tunnels) in planning and one under construction (Flirsch tunnel). In future, the energy produced will be used directly for the operation of the tunnel facility. The predicted annual production using Semmering tunnel as an example is around 490 MWh, with an output of 55 kW. For the small hydroelectric power plant at Karawanken tunnel, a capacity of 27 kW and an annual production of 230,000 kWh is calculated. These examples clearly show that on the one hand, attention must be paid to the available line (MW/kW) and on the other to the energy that can be produced (MWh/kWh).

7. WHAT ABOUT THE FUTURE? BATTERY STORAGE SYSTEMS FOR TUNNEL OPERATION

The Netherlands Knowledge Centre for Underground Space and Underground Construction (COB) has developed the vision of the "Zero Energy Tunnel". The outlook for 2020-2030 outlines a future scenario which is very important “What opportunities does a tunnel provide for energy generation and storage?” [9]

7.1. Use of electrochemical storage technologies (batteries)

The "Austrian Institute for Technology (AIT)" has drawn the following scenario within the framework of a study "Temporary storage facilities of the future for electrical energy": Regenerative electricity generation via hydropower or photovoltaics depends on the current natural supply. In addition, the consumption profiles – i.e. the daily or seasonal demand for energy – often do not correspond to the generation profiles. One possible solution to this challenge is storage technologies. Industrial battery storage systems are usually electrochemical storage systems, which are primarily used as time buffers. This enables, for example, high power to be delivered at short notice while the grid load remains constant. Energy storage and decentralisation in the context of global trends and future risks are described as "small, distributed energy systems that use renewable energy sources and do not require connection to a public power grid". This would also increase the resilience of energy systems and critical energy infrastructures to natural disasters [10].

Thus, such solutions are also an ideal optimisation tool for energy supply to tunnels, and could also perform several functions for stable operation:

- Storage of the generated renewable energy
- "Load Shift" – shifting of the generation peak from day to night
- Emergency power function in case of power supply failure

7.2. ASFINAG case study S01 Wiener Außenring expressway

The S01 Wiener Außenring expressway is 16.2 km long in total. It is a very busy route with up to 100,000 vehicles per day in the Vienna area. There are six tunnels with a total length of about 4 km on the route. In addition, extensive technical facilities are in operation in addition to the tunnel systems. For example, continuous open-air lighting, traffic control systems and pump systems, etc. The current energy requirement under different operating scenarios is as follows:

	Normal operation day	Normal operation night	Fire Vösendorf tunnel	Fire and heavy rain
Operating status	---	Night setback tunnel and open field lighting	Ventilation systems	Ventilation systems and pumps in open space
Energy demand	580 kW	500 kW	1330 kW	2,270 kW

Figure 4: S01 Energy demand in different operating conditions

At present, the possibilities of covering the energy demand with photovoltaic systems are being examined. Due to the existing areas along the route and at the tunnel systems, a large amount of energy production could be implemented. According to initial surveys, around 4,200 photovoltaic modules could be installed. Depending on the module output used, up to 1,500 kWp production output is possible.

This means that considerably more energy would be produced than can be consumed in normal operation during the day. Since continuous energy distribution via a medium voltage system is also possible along the route, a sensible scenario with several battery storage units and a total of 6 – 8 MWh is possible. This solution would not only result in optimised energy utilisation, but would also provide for excellent bridging in case of a blackout, at least for normal operation, over a period of 10 hours. This would also mean that there would be no operational restrictions as described in point 4.2.

8. SUMMARY AND CONCLUSIONS

The current emergency power supply is only designed for a minimum and has no added value with regard to the energetic use of renewable energy production. Only a minimum supply of some plant components is provided for and is only used for emergency operation. In many tunnel systems, however, the use of diesel emergency power generators is not appropriate for full operation due to the power required in the event of an incident. The reason for this is that they are expensive to purchase, maintain and service. Even emergency contracts with external provision will only help to a limited extent in the event of a blackout.

In this case, the use of battery storage as an alternative to diesel generators should be evaluated. Especially due to the additional benefit of storing generated renewable energy, the use of this energy for operational management at night and a full-value replacement power supply in case of a power failure. As an additional benefit, the island operability and independence from power grids becomes very interesting and can also serve as a regulating element for the entire energy system to keep the entire power grid stable. In general, this aspect will play a very important role in the future, but the overall economic efficiency must be evaluated. Here, the advantage would be that, for example, the current emergency power concepts could be rethought and saved.

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