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Advanced Features of Static Inverter and Their Influence on Rail Infrastructure and Vehicle Maintenance

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Abstract

Static inverters are essential devices onboard of rolling stock. State-of-the-art static inverters have an impact on both rail infrastructure and vehicle maintenance due to their new topology with new features.

The paper describes two important aspects as examples of new features available in state-of-the-art static inverters: active input current control and the effects on the rail infrastructure as well as the detection of the state of charge and the state of health of batteries to simplify vehicle maintenance.

Keywords : *Static inverter, Rolling stock, Soft-switching, Medium frequency transformers, Active input current control, Interoperability, Batteries, State of charge detection, State of health detection*

1. State-of-the-art Static Inverter

Static inverters are an integral part of the rolling stock and the requirements continue to increase. They have to become more and more powerful while they should also become smaller, lighter, more efficient but with minimum influence on other equipment in both the rolling stock or the infrastructure.

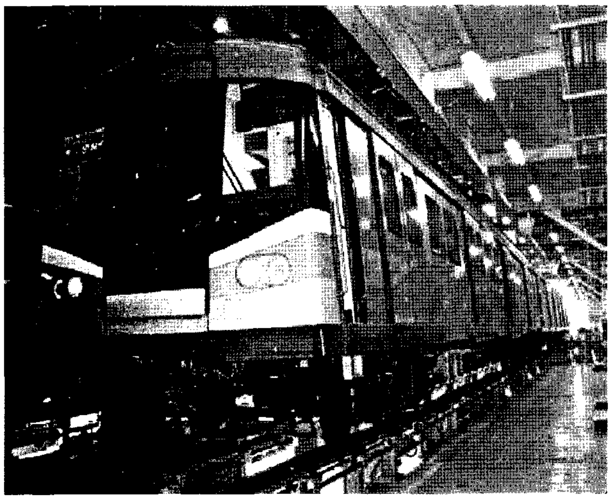

Fig. 1. New Metro Kaohsiung Rolling Stock Using State-of-the-art MEE-NT Based Static Inverter

At first glance these criteria seem to require optimization in different directions. However, static inverters offering a very good compromise between the different requirements are available as proven solutions.

One of the solutions available is the MEE-NT based line of static inverters designed and manufactured by SMA Technologie AG, Germany. A good example of such state-of-the-art static inverters is used for the new rolling stock for Metro Kaohsiung.

Each three-car metro train is equipped with two SMA-made MEE-NTSD static inverters with an integrated battery charger and a rated power of nearly 160 kVA, each. The static inverters are directly fed from a 750 V DC third rail.

The static inverters are underframe mounted and with less than 850 kg exceptionally light. Soft-switching technology for the semiconductors enable the use of compact and low-weighted medium frequency transformers. The static inverters are designed for maximum efficiency. A peak efficiency of 96% is reached [1,2].

The introduced MEE-NTSD static inverter is exceptionally light, small and highly efficient. But how is the influence to other equipment both on the rolling stock as well as within the infrastructure managed?

2. Active Input Current Control

In order to reach the highest possible efficiency of the

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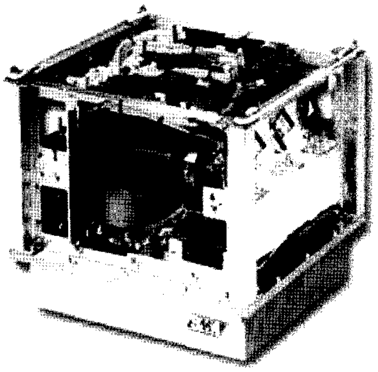

Fig. 2. Input Converter Module Featuring Active Input Current Control

total rail system the static inverter should be a *minimum* load for the supplying infrastructure. Of course, the loads connected to the outputs of the static inverter have to be supplied. But the RMS value of the input current into the static inverter must be as low as possible. At a DC third rail or catenary the static inverter should draw a pure DC current while at an AC catenary the input current should be sinusoidal and in phase with the input voltage.

Conventional static inverters connected to a DC third rail or catenary are equipped with a large passive input filter. While the input capacitance is usually given due to the requirements of the internal power electronics an input inductance must be chosen to ensure an inductive behaviour and a certain cut-off frequency of the input filter. The needed input inductance is usually large and heavy. On top of that a large inductance is not easy to handle during short input voltage interruptions and as a result of rising copper prices becomes more expensive.

MEE-NT based static inverter come with an active input filter. The active input filter consists of an input inductance, a step-up converter and a comparatively very small capacitor (a few μF). This capacitor is used as resonance capacitor for the connected soft-switching inverter.

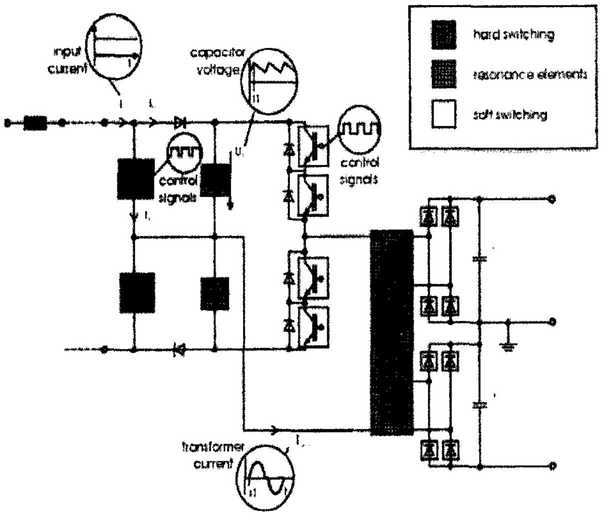

Fig. 3. Principle Circuit Diagram of MEE-NT Based Input Converter Module

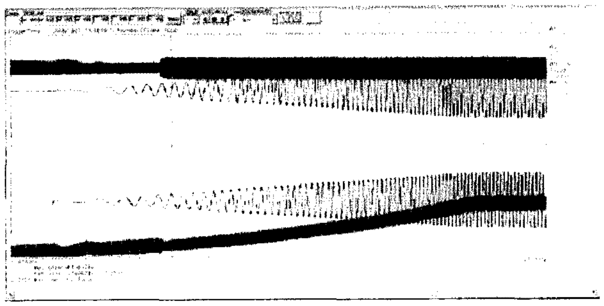

Fig. 4. Start-up of a MEE-NTSD Static Inverter for Metro Kaohsiung

The voltage across the resonance capacitors is always higher than the maximum input voltage arising on the line. Therefore, the input step-up converter can actively control the input current. This is especially easy for lower input frequencies where a passive input filter is almost useless.

The objective for the project in Kaohsiung was to increase the overall efficiency of the rail system by reducing the 300 Hz ripple current on the third rail without the need for large input inductances for the static inverter. A large input inductance would have been a solution for the 300 Hz input current suppression. But it would add a significant amount of weight onto the rolling stock increasing the power consumption due to the increased traction effort needed.

A better solution is to use the available features of the MEE-NTSD static inverter. An active 300 Hz input current suppression is implemented. The 300 Hz current in the system is not generated by the static inverter or by the connected loads. The current source is the DC traction power supply.

Figure 4 below shows the start-up sequence of a static inverter with loads already attached. The top chart shows the voltage on the third rail and the output voltage of the static inverter while the bottom chart shows input current and output current of the static inverter.

During the start-up sequence a 300 Hz input current suppression control is activated. This is indicated by a sudden decrease in the 300 Hz input current while at the same time the ripple voltage on the third rail increases to nearly no-load conditions. Additionally, the 300 Hz input current into the static inverter does not depend on the load and does therefore not change during operation.

Figure 5 below shows the activation of the 300 Hz input current suppression control in more detail. Only input current (bottom) and voltage (top) are shown in the chart.

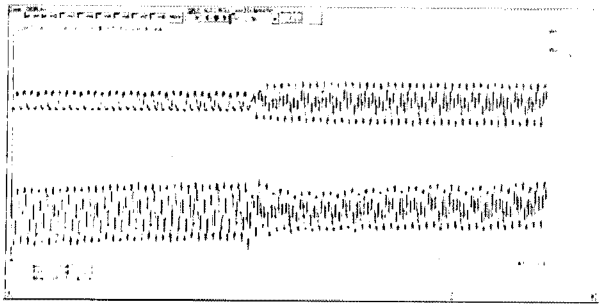

Fig. 5. Start-up of a MEE-NTSD Static Inverter for Metro Kaohsiung

The objective of the active 300 Hz input current suppression is to increase the efficiency of the rail system. Therefore, the performance of the system is not safety critical.

However, there may be other input currents that must be avoided to ensure a secure operation of the rail system. This is especially critical when new rolling stock is introduced on existing infrastructure.

Very often e.g. track circuits to detect trains on certain parts of the infrastructure or to count axles are being used. Most of the time such circuits function electrically. As an example a voltage of a certain frequency can be used in such systems to detect an approaching train by a change of the impedance of the system.

Therefore, it is absolutely important, that the rolling stock used on the infrastructure does not interfere with the signaling equipment used. Any rolling stock being used shall not emit distortion currents, voltages or electrical fields that may interfere with the signaling equipment. Furthermore, the rolling stock needs to have a defined electrical input impedance in order to prevent e.g. a short circuit of any voltage signal used for the signaling.

The requirements on the limitation of any distortion being emitted by the rolling stock as well as the requirement of a defined input impedance also applies to the static inverter as one of the main electrical systems onboard a train. Again, the requirements can be fulfilled by using passive and active solutions.

Especially in case of old infrastructure, signaling systems with low operational frequencies are being used. To ensure a defined input impedance at signaling frequencies as low as e.g. 75 Hz, a large input inductance is required if only passive solutions are used. The situation becomes even more difficult if static inverters are used in parallel for redundancy reasons or if individual cars are combined to large trainsets. The defined input impedance is required per trainset. The more electrical subsystems are in parallel operation the larger is the individual input impedance for each subsystem needed.

The above-introduced 300 Hz input current suppression for the new Metro Kaohsiung rolling stock can be considered as a defined input impedance for the static inverter at 300 Hz. The described control also functions at other discrete frequencies. Furthermore it is even possible to set-up a defined input impedance over a complete frequency range up to 1 kHz. For higher frequencies the necessary input filters are rather small and the increased efforts for an active input impedance control at higher frequencies are not justified.

A major consideration is the safety criticality of the active input impedance control. It is certainly more difficult to prove the reliable operation of an active solution compared to a passive input filter. However, the advantages in terms of less weight, smaller dimensions, better flexibility and higher efficiency are obvious. The first European railways operators have either already approved static inverters with active input impedance control or are in the process to do so.

3. Battery Maintenance

Batteries are essential for the continuous supply of electrical loads in all railway vehicles. Both the general availability and a sufficient charge state are fundamental, especially when it comes to powering safety critical devices.

In most cases, extensive service and maintenance work is performed to ensure the availability of the battery. Test systems are often used to acquire the state of charge as well as the state of health of the battery. To do so, the batteries must generally be disconnected from the static inverter. This is being done during scheduled maintenance in the depot. Using the testing equipment, the battery is specifically subjected to a defined discharge current for a short period of time. The charge state is acquired and the aging state of the battery is diagnosed using the self-adjusting terminal voltage.

This is time-consuming and must be repeated in regular, mostly short intervals - resulting in high costs for the operator. Furthermore, assessing such information only using the terminal voltage is often not sufficient.

Modern static inverters are already equipped with all the current, voltage and temperature sensors required for gentle battery charging. These sensors also allow a sufficiently precise assessment of the state of charge and the state of health of the battery. This assessment can be done continuously with more precise results but without any scheduled maintenance necessary.

To achieve this, the ampere-hours of the charge and discharge currents are gradually balanced. However, converting electrical energy into chemical energy or back involves losses. These losses and the inaccuracy of the acquired measured values are taken into account by the loss monitoring during the ampere-hour balancing.

For rolling stock the accuracy requirements for ampere-hour balancing are quite minor compared with other applications. In most cases, the battery on a railway vehicle is charged for a long period of time and at regular intervals and is only discharged for a brief period of time. With a well-designed system, the fully charged state is thus consistently and frequently reached. The fully charged state can then be used to recalibrate the system.

Using any available interface, the information on the state of charge can be forwarded to the vehicle control. It is possible to e.g. generate a warning message, if the state of charge falls below a defined parameter.

The battery capacity generally decreases during the battery's lifetime. Under certain circumstances, if the battery capacity drops below a specific value, the sufficient supply of the loads is no longer ensured. In such cases, the battery must be maintained or replaced.

A modern static inverter with integrated ampere-hour balancing, loss monitoring and recalibration can detect a decreasing battery capacity. The information on the state of charge is always based on the state of health of the battery and therefore more precise. This is especially true for batteries close to the end of their lifetime and under challenging ambient conditions that are common for rolling stock. In addition, the static inverter can detect maintenance needs, which can also be forwarded to the vehicle control using the available interface to request unscheduled maintenance on the rolling stock.

Up to now, rail operators have been reluctant in using the procedures mentioned above for the state of charge and the state of health detection of the battery on rolling stock, even though it would yield an additional savings potential. In contrast, battery inverters or UPS systems are using this technology for years.

The SUNNY ISLAND bidirectional battery inverters, which were developed and are manufactured by SMA, have been utilizing such procedures for years. In this case, batteries used in systems for renewable energy applications reach their fully charged state considerably less frequently. The requirements for loss monitoring and recalibration are thus disproportionately higher.

However, the feedback on the SUNNY ISLAND's performance over the last few years has been very positive. The precise assessment of the state of charge and the state of health of the battery even extended the lifetime of the battery significantly by avoiding overcharging and deep discharge.

Today the users of the SUNNY ISLAND bidirectional battery inverter are very confident of the technology. The battery capacity originally designed in the systems is decreasing because the precise assessment of the state of charge and the state of health of the battery allow an optimum usage of the battery capacity installed. Extra capacity for safety reasons becomes less and less necessary.

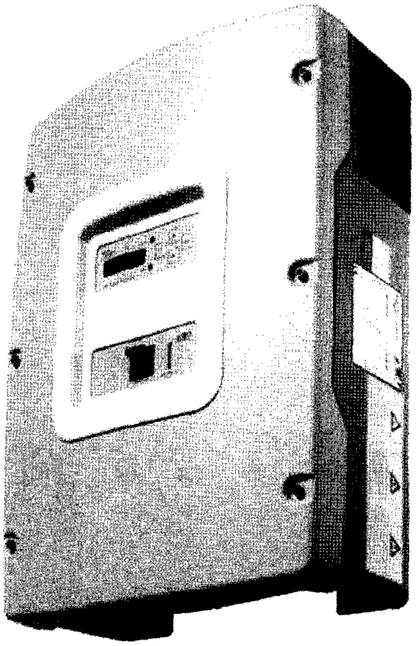

Fig. 5. SMA Made SUNNY ISLAND Bidirectional Battery Inverter Using an Advanced State of Charge and State of Health Detection for the Battery

The available technology allows to precisely assess the state of charge and the state of health of the battery. Smaller batteries can be used, while the lifetime is extended, and unnecessary maintenance work is avoided which decreases investment and maintenance costs significantly.

4. Conclusion

State-of-the-art static inverters offer new features that allow to e.g. increase the energy efficiency of rolling stock or to decrease the maintenance needed on some subsystems.

Static inverters using active input current control are a proven solution and will become the first choice of railway operators since the energy efficiency of the total rail system becomes more important. Even the use of active input current control for safety critical application will become more common.

Systems to assess the state of charge and the state of health of a battery have proven their reliability. Since the advantages are multifarious and the additional costs for installation are very low compared to the cost saving potential during the maintenance, such systems will become a standard for new rolling stock in the near future.

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Bibliographies

1. Bachmann, G., studied Electrical Engineering at the Darmstadt University of Technology (TUD). After receiving his M.S. degree in Power Electronics he worked on resonant switching topologies at the Institute for Power Electronics and Control of Drives at the TUD. At SMA he started as a development engineer. Meanwhile he is responsible for the new development group at SMA's Railway Technology Business Unit.
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