Use of Fronius string inverters in large-scale PV systems

and their effect on the system as a whole

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1 INTRODUCTION

There is no one single aspect that determines the optimum design of a large-scale PV system, as in every project there are numerous technical and commercial considerations that have to be compared and modified to reflect the individual wishes of the customer and the local circumstances. Apart from selecting the most appropriate inverter, the choice of system design is pivotal to the project.

This paper examines the operational capability of string inverters in large-scale PV systems. The inverters are represented in varying system designs and the technical and commercial product requirements studied. The benefits and effects on the commercial system as a whole are discussed. Finally, the practicality of string inverter concepts is exemplified with the help of an example system.

2 INVERTERS FOR LARGE-SCALE SYSTEMS

When considering large-scale PV systems, a basic distinction is made between two system concepts: those in which string inverters are used and those that favour a central inverter. The following sections look at the broad operational capability of string inverters and consider their application potential in large-scale commercial systems.

2.1 The string inverter

The modern definition of a string inverter is an inverter whose output ranges from a few kilowatts to around 100 kW. It can be fitted directly to a wall, to a vertical support, or even installed horizontally. A string inverter is generally compact, making it easier to transport and requiring only 1 to 3 people for its installation.
They can be found in residential settings as well as in commercial projects. In large-scale PV systems, string inverters are used in roof-mounted systems and in outdoor installations.

2.2 The requirements

Because large-scale PV systems need to be implemented in a cost-effective manner, factors such as flexibility, ease of use, functionality, performance, and price/performance ratio are crucial when choosing the best inverter for the job.

2.2.1 Flexibility in planning

String inverters cover a broad application area. They can be installed on a roof, inside or outside a building, right next to the PV modules, directly at the transformer station, on a support or horizontally on the ground. Their relatively low weight and compact dimensions make the whole planning operation considerably more flexible, as no modifications to infrastructure have to be made or heavy lifting gear arranged in advance. String inverters are particularly advantageous for installations where the strings within a PV system have varying roof or slope orientations. If the project requires, string inverters of differing sizes and functionalities can be mixed within a PV system, and any revisions can be carried out much more easily and with a greater degree of flexibility.

2.2.2 Simple installation and commissioning

The fact that string inverters are comparatively low in weight and usually have an extremely compact footprint makes them very straightforward to transport: no heavy-duty machinery, cranes or HGVs are necessary. Fronius string inverters can be installed and commissioned very quickly, an added benefit being that this can be done directly by an installer on site. The advantages of compact string inverters with regard to handling and transport come to the fore in locations that are difficult to access, such as open spaces with no metalled access roads or on roofs that are only accessible using ladders.

2.2.3 Maximum performance for high yields

The yield of a PV system depends on a number of factors, such as insolation, efficiency, the cooling system or even partial shading of the solar modules. String inverters boast a high level of conversion efficiency.

Climatic conditions, such as the effect of heat or direct sunlight on the device, have a marked influence on the yield of the PV system as a whole. Fronius string inverters have an active cooling system and a professional power derating behaviour. These combine to deliver maximum yield for longer, even at temperatures as high as 50°C, which has a positive impact on yield figures. In warmer regions in particular, devices featuring active cooling technology deliver considerably higher yields, resulting in shorter payback periods.

2.2.4 Prompt service for dependable yields

The dependability of the yield of a PV system utilising string inverters is guaranteed by two important factors. Firstly, the string inverter concept increases supply reliability, as only a small part of the system is affected by a failure (e.g. 27 kW in the case of the Fronius Eco). This means that a string fault or downtime due to servicing activities has less of an impact on the overall yield. As string inverters can be equipped with sophisticated string monitoring features, any faults that do occur can be limited in advance to a particular module array without the need for someone to have to drive out to the site. Secondly, thanks to their compact design, string inverters can be replaced quickly and easily. With Fronius inverters, some specific components can be replaced by a single person, offering the system operator flexibility over the entire service life of the PV system, as spare devices or components can be held on site to ensure a rapid repair in the event of a fault. This process keeps service costs down, guarantees yields and means that the PV system will only be offline for a short period, as servicing can be carried out quickly and easily by a local installer.

2.2.5 Savings potential

The fact that most types of string inverter can usually be mixed very easily within a PV system not only simplifies the planning (compared with central inverters), it can also keep the initial costs down. For example, the system planner can design the bulk of the system to use string inverters equipped with 1 MPP tracker, while reverting to a string inverter with multiple MPP trackers for complex or shorter strings.
The active cooling of string inverters not only ensures higher yields, even at higher temperatures, it also extends the service life of the device through improved cooling of the power electronics. This also lowers costs and shortens the payback period.
Moreover, PV systems that use string inverters can in most cases be designed to operate at the low-voltage level, resulting in lower outgoings for transformers. In situations where string inverters – operating at 1500 V, for example – are installed at the medium-voltage level, a second low-voltage transformer will be required as soon as the PV system is used for self-sufficiency in a 230V/400V grid. Unless specified otherwise by the grid operator, the string inverter concept also allows the required measuring system to be integrated into the low-voltage level, once again lowering costs due to the significantly cheaper measuring equipment and sensors available for this level.

3 DESIGN OF LARGE-SCALE SYSTEMS WITH STRING INVERTERS

There are a number of reasons why string inverters are nowadays used in many large-scale PV systems. Local circumstances will basically determine which of two different topologies is used in the design of the system.

3.1 Decentralised system design

In the past, string inverters tended to be decentralised and located close to the PV modules. In a decentralised system, the inverters are located right next to the PV module array, either individually or in small groups. Longer distances are bridged using AC cables connected either directly to the main AC distributor or in groups in an AC sub-distributor. This keeps DC cable lengths short and enables greater distances to be bridged using AC cables.

Figure 1: Structure of a decentralised system

3.1.1 Decentralised individual string inverter configuration

An individual inverter configuration is chosen when the inverters are to be distributed in the field and installed next to the PV modules. This allows the module strings to be connected directly to the inverter, reducing the need for DC and AC collector boxes. Each string inverter is then connected separately via AC cables to an AC main distributor located close to the transformer station.
Typical application areas for this type of system design are the roofs of commercial and industrial buildings and small to medium-sized outdoor PV installations.

Figure 2: Individual string inverter configuration in a decentralised system

3.1.2 Decentralised grouped string inverter configuration

String inverters can also be configured in groups next to a row of PV modules, with the DC cables connected directly to the inverters. The cables on the AC side are collected together in an AC distributor. The respective AC distributors are connected to the main AC distributor next to the transformer station by an AC cable.
This type of system design will be found on the roofs of industrial premises with little space for inverters and in large outdoor installations that have to be readily accessible for installation or maintenance purposes.

Figure 3: Grouped string inverter configuration in a decentralised system

3.2 Centralised system design

Besides a decentralised system design, it is also possible to implement what is known as a centralised system design with string inverters. Here, the inverters are placed close to the transformer or main distributor and linked together using DC collector boxes. The DC collectors are located in the vicinity of the PV modules, from where heavy-duty DC cables lead to the string inverter. DC cables therefore cover most of the distance between the module array and the inverter. By contrast, the distance covered by the AC cables is relatively short.

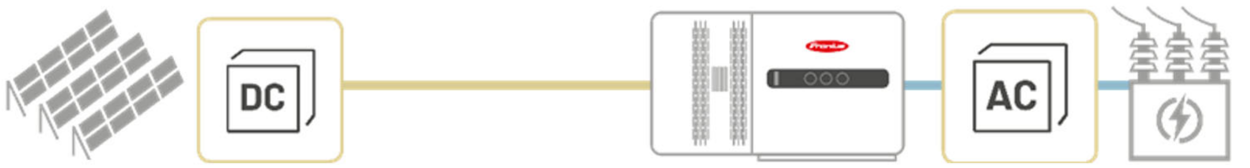

Figure 4: Structure of a centralised system

The module strings of a centralised system are brought together in a string collector box and routed via a main DC cable to the grouped string inverters. Separate AC cables lead from the string inverters to an AC distributor, from where a main AC cable leads to the transformer.
Application areas are the roofs of industrial premises with a separate inverter room, for example, or outdoor installations where the inverters are to be located at a central servicing point close to the transformer station.

Figure 5: Centralised string inverter configuration in the vicinity of the main distributor

3.3 Mixed and special types of system design

Local circumstances and the requirements arising from them can give rise to the need for mixed or special types of system design. For example, part of the PV system may have to be implemented using decentralised string inverters while another part may require them to be grouped in a central location.

3.3.1 Decentralised design with AC daisy-chaining

AC daisy-chaining is a Fronius technology that permits inverters from the Fronius Tauro product range to be chained together on the AC output. This is achieved using an AC distributor integrated into the inverter.
This special design option enables a number of string inverters rated at up to 200 kW to be chained together on the AC side, thus reducing the amount of AC cabling required.

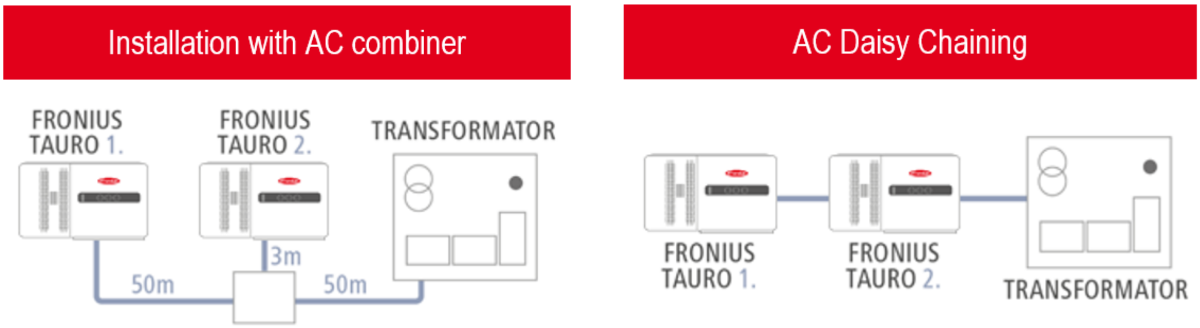

Figure 6: Comparison of direct connection and connection using AC daisy-chaining

Using this design option enables the decentrally located string inverters to be connected directly to the module array with DC cables. However, the inverters are not connected individually to the transformer station on the AC side, but are first made into a group (e.g. 200kW), meaning that the AC line only has to be routed from one inverter to the next, rather than over the much longer distance to the transformer. The daisy-chained inverters are then connected to the transformer using a common AC cable. This approach can be adopted in both a decentralised individual configuration as well as a group one.

Application areas for this type of system design include the roofs of industrial premises and larger outdoor installations in which large distances exist on the AC side between multiple string inverters and the transformer.

Figure 7: AC daisy-chaining with Fronius Tauro ECO in a decentralised group configuration

3.3.2 Centralised design with AC daisy-chaining

The Fronius AC daisy-chaining option can also be used when the string inverters are centrally located. Even though the AC cable is relatively short compared to the DC cable, linking a number of string inverters together in an AC daisy chain is a convenient way of reducing the installation effort and the amount of AC cabling required.

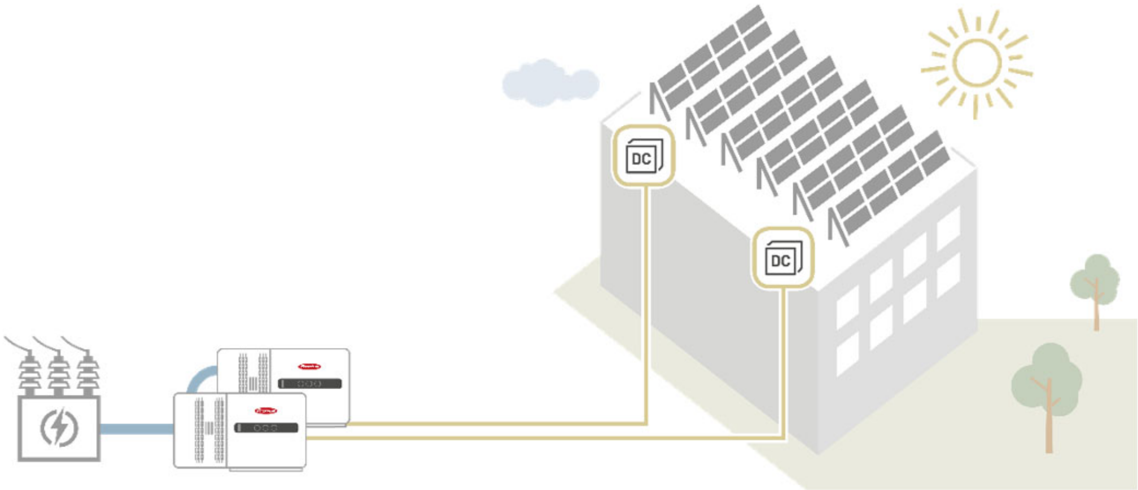

Figure 8: AC daisy-chaining with Fronius Tauro ECO in a centralised system

3.4 Criteria for deciding which system design to select

All things considered, the decision whether to install a PV system as a decentralised, centralised or in a mixed or special configuration depends on the local and structural conditions.

3.4.1 Accessibility in the case of roof-installed systems

Not every roof on which a PV system is to be installed is always readily accessible. In many cases there are no stairways or fixed ladders. In such cases installing the inverter on the roof may well turn out to be a false economy, as if the roof is difficult to access, the cost of hiring scissor-lifts or similar equipment during installation and maintenance activities will quickly mount.

Since string inverters are extremely flexible in terms of the system design, additional hidden costs are easily avoided. Factors such as installation, maintenance and servicing need to be considered during the planning phase to enable the most cost-effective system design to be chosen.

3.4.2 Required structural measures

Thought needs to be given to a number of points. For example, what can be done to simplify the installation of the inverter, as factors such as its physical mounting and shading structures will need to considered well in advance. In many situations, the bracing of the solar module substructures can also be used as supports for the string inverters. If this is not possible, additional supports will have to be installed.
The same applies to the shading structures. If a room is available where the inverters can be installed, then shading will not be an issue. Otherwise, structural measures, such as the erection of canopies or containers, will have to be undertaken. String inverters have an advantage over central inverters in that they are both more compact and lighter, so simply putting them underneath the solar modules will provide adequate levels of shading.

3.4.3 Distances and dimensions

With every PV system, it is essential to consider the distances between the module array and the main distributor in advance. Cable lengths and costs, and the associated requirements placed on the cable and its cross-section, often determine the type of system design. With long distances in particular, yield losses from cables must not be ignored.

3.4.4 Conditions at outdoor sites

Last but not least, another important factor dictating the choice of system design are the surroundings around the site of the outdoor installation. Depending on the local conditions, an outdoor installation is sometimes easy to access, sometimes difficult. If an HGV or other heavy machinery is to be used, metalled roads are a must, a requirement that can drive up overall costs. Due to their relatively low weight, string inverters once again prove their flexibility, as an HGV will not be required. The location of the inverter can also be chosen to ensure there is no need for a crane.
It is not just the transport and positioning of the inverter that can pose a challenge: uneven terrain can result in a number of different module orientations within a PV system. This is another area where a decentralised system of string inverters is advantageous. In addition, many string inverter models are also equipped with multiple MPP trackers, which greatly simplifies the design of complex systems.

All these factors have a real influence on the choice of system design. However, the flexible application options of string inverters allow the most cost-effective system design to be selected for every project.

4 EXAMPLE OF A MULTIPLE MW SYSTEM WITH STRING INVERTERS

Tokmak is a small town in the south of Ukraine. In 2018, a local company – Tokmak Solar Energy – completed Ukraine's largest PV system.

4.1 Key data

This commercial photovoltaic system is an outdoor system with a PV output of nearly 52 MWp and an annual yield of approx. 67,000 MWh. For this large-scale system, Tokmak Solar Energy decided to use string inverters, resulting in the installation of a total of 1,923 Fronius Eco inverters.

SYSTEM DATA	TOKMAK, UKRAINE
System size	51.9 MWp
System type	Outdoor installation
Module type	Talesun TP672P
Inverters	65 x Fronius Eco 27.0-3-S 1,858 x Fronius Eco 27.0-3-S light
Annual yield	Approx. 67,000 MWh
Commissioned	October 2018

Table 1: Overview of the system

Figure 9: Aerial view of the large-scale PV system at Tokmak (photo credit: Fronius)

When implementing its PV system, the focus of Tokmak Solar Energy was to keep the DC cables as short as possible so as to reduce the balance of system (BOS) costs. BOS costs are part of the initial costs and are essentially made up of the costs for cabling, string collectors and other vital system components. The shorter DC distances seen in the Tokmak Solar Energy project meant that not as many DC distributor boxes were required.

4.2 The system design

In order to realise the short DC distances, Tokmak Solar Energy opted for a decentralised system design in a grouped string inverter configuration.

Figure 10: Example showing the groups of 4 inverters - Tokmak system (photo credit: Fronius)

The string inverters are grouped into 100 kW units, with the inverters distributed decentrally in groups across the entire system. The large-scale 52 MWp system consists of individual subsystems that are each connected to their own transformer station. These decentralised subsystems have been duplicated to produce a multi-megawatt system.

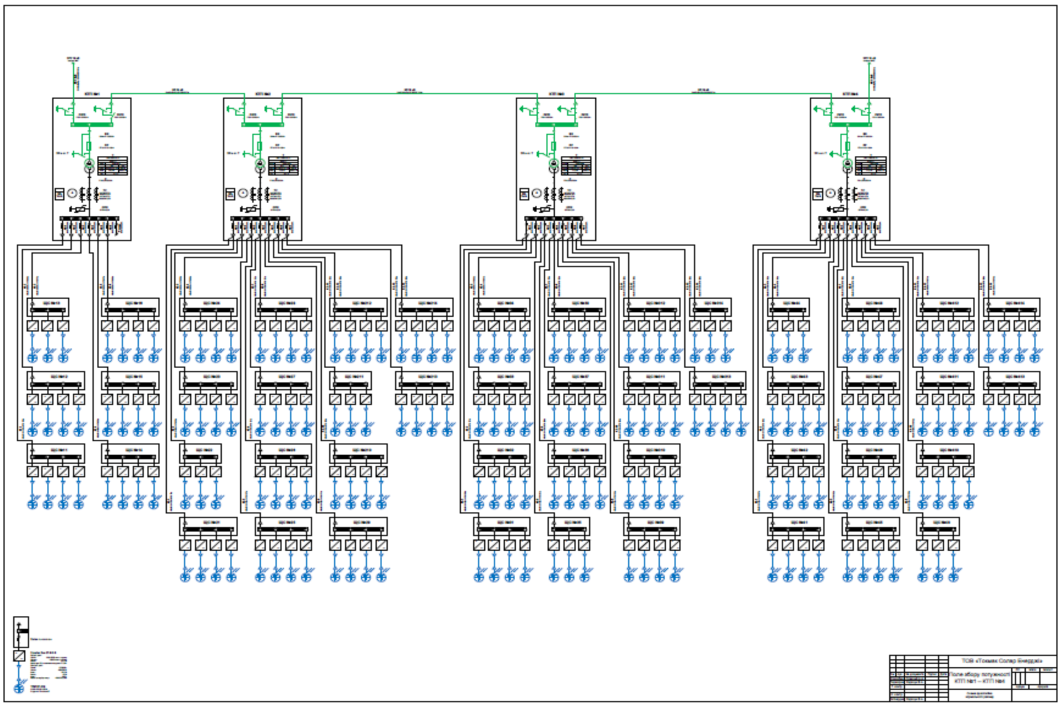

Figure 11:: Decentralised design based on string inverters - Tokmak system (photo credit: Fronius)

4.3 Installation & commissioning

Tokmak Solar Energy was able to keep its costs extremely low when installing the Fronius Eco string inverters. The Fronius inverters use what is known as SnapINverter technology to simplify and speed up the installation process. Fronius string inverters boast a protection class of IP66, which means they can be positioned in unsheltered outdoor locations, which allowed Tokmak Solar Energy to dispense with any additional housings. As these structures were not required and the system components, such as a datalogger, were already integrated, BOS costs were also kept to a minimum.

With interfaces and protocols integrated as standard, Tokmak Solar Energy was also able to implement a detailed operational monitoring system at very little extra expense.

4.4 Advantages of the system concept

Yield dependability was at the forefront for Tokmak Solar Energy in a project of this magnitude. Should a problem ever occur with an inverter, a prompt solution had to be on hand and any yield losses kept to a minimum.

As described in section 2.2.4, a system concept built around string inverters means that only part of the system is affected in the event of a fault or when any servicing has to be carried out. Whenever maintenance or testing is necessary, individual parts of the system can be switched offline as required without incurring any significant loss of yield. When servicing, a Fronius Eco string inverter can be quickly and easily replaced on site by a single person. However, Tokmak Solar Energy decided to contract a local Fronius System Partner (FSP) to carry out any service work. This is facilitated by the Fronius PC board replacement process, which means the complete device does not need to be replaced. This process enables Tokmak Solar Energy to react in a timely and extremely cost-effective manner to any faults that occur, minimising downtimes and the resulting yield losses.

Tokmak Solar Energy is also able to speed up the troubleshooting process in its large-scale PV system, as the Fronius Solar.web system monitoring tool enables faults to be pinned down to a particular part of the system in advance. If, for example, an overvoltage fault occurs, the installer receives a message from Solar.web, enabling them to react immediately and fix the fault; this simplifies and also accelerates the service callout.

Another aspect that Tokmak Solar Energy saw in favour of string inverters for this project was the active cooling technology employed by Fronius inverters. The active cooling system keeps ongoing maintenance costs down, as it does not specify any maintenance intervals. In addition, the fans prevent any hot spots and temperature rises from occurring inside the string inverter and extend the service life of electronic components.

5 SUMMARY

String inverters boast a number of features that make them ideal for large-scale commercial PV systems. Their characteristics offer system planners a high degree of flexibility. The choice between a decentralised or centralised system design, or a mixture of the two, allows plans to be tailored exactly to the individual requirements and circumstances, and to the PV system itself. Flexible system planning and occasional revisions are, in the case of large-scale PV systems, sometimes necessary in order to end up with a cost-effective overall system.

With their compact design and relatively low weight, string inverters not only increase planning flexibility, they also simplify transport, installation and commissioning, hence saving time and keeping costs down.

Within the system as a whole, string inverters operate as autonomous power units, leading automatically to a lowering of risk. In the event of a fault, only part of the PV system goes offline, resulting in lower yield losses than would otherwise be the case.

With an eye on OPEX and the objective of keeping total costs as low as possible, string inverters are proving to be extremely time-efficient with respect to service callouts. The string inverters allow components or devices to be replaced quickly and easily by just one person. This minimises the high costs associated with service visits and reduces yield losses where large parts of a system are out of service for an extended period.

The features discussed above and the range of functions of Fronius string inverters enable system owners to develop a cost-effective and large-scale PV system according to their individual requirements.

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