

Development and demonstration of a system that enables PV sun-tracking installations to supply ancillary services to the grid

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Abstract

An innovative, cost-effective and easy to install technology is introduced that allows PV sun-tracking systems to regulate their production according to the demand. This technology combines both control-automation and communication tools, in order to adjust the PV power production to the consumers, to the needs of the electricity grid operator and to the power market. The main idea is to use the sun-tracking system, i.e. by changing the position of slave trackers, for achieving not the maximum possible power output but the desired one. The proposed system is also able to calculate the maximum power and measure the lost power, therefore enabling charging and market integration potential. The system can be adjusted to almost all sun-tracking systems, whereas the signal transmission towards the PV system can be accomplished both by Digital Audio Broadcasting (DAB) energy data transmission protocol and by ripple control.

1. Introduction

In many European Union (EU) countries, the laws allow premium access to the grid for RES. Consequently, weather-dependent RES, such as PV-plants and wind-farms, operate at their maximum possible outputs whenever technically possible and therefore do not follow the variation of energy consumption. In high RES penetration cases and especially whenever local grids (e.g. microgrids) or isolated energy networks (e.g. islands) are considered, the above operational principles and trends include the risk of reduced reliability of power supply to the consumers. For example, at many rural and low-populated areas in Greece, the power that is produced by DGs at specific hours during a day exceeds the local demand, leading to local overvoltage and DGs outages. Therefore, the ancillary services that could be provided by the supply-side and the demand-side are expected to increase the value of the future smart grid [1]-[6]. Load leveling and demand-side management are extensively used in general to provide services like voltage regulation and energy management for islanded microgrids [2], [6], [7].

In [8], some of the authors proposed a technique that is applied in stationary PV systems and uses relays to control the output of the PV strings and thus the output power of the whole

PV plant. However, the system could not estimate a-priori the reduction or increase of the output power and could not estimate the lost power. Therefore, the market integration potential was limited.

In this paper, the authors propose a system that uses the sun-tracking system of PV plants, for achieving not the maximum possible output power but the desired one. It basically bypasses - changes the position of slave trackers and can be adapted easily to all existing trackers. In a step-by-step description procedure, initially, a power measuring device is installed at the output of each inverter, for measuring the power and energy produced by each inverter. Then a device that collects the inverters output data is utilized, so that the system has the advantage for online monitoring. Having in mind that the majority of trackers are controlled by PLC using a time algorithm, the operation of the system is as follows:

After checking the integrity of the trackers, the system changes the position only of the slave trackers, initially by moving them to the east and then by lagging behind the master trackers according to the desired reduced output power. The main challenge is to take control of the existed tracking system without changing it. So the cost will not be increased enough. The idea is to run a parallel system which will take control when it is necessary.

2. Proposed control system for the ancillary service of PV plants with sun-tracking systems

2.1. Description of the control infrastructure

The control infrastructure design is based on the following concept: In case a distribution transformer has reached saturation, a command reaches the PV power plant that supplies that transformer of the substation. According to the command, the proposed control system regulates its energy production, i.e. it forces a pilot base to follow the course of the sun, having it as reference point and corrects the direction of the other trackers, so as to achieve the production that the command dictates. Thus, the PV power plant reduces its power production, calculating at the same time the energy that should have been produced.

The operation is done in the following way: When the authors' system receives the message, it starts causing diversion tracking, except from the master tracker, which continues to follow the sun optimally. The drift of the secondary trackers is

usually to the east direction (opposite of the master tracker). Then the slave trackers begin lagging behind the master trackers, in such an angle that can achieve the desired output power. The control algorithm is a Perturb and Observe (P&O) algorithm: For example, after receiving the command, the P&O algorithm forces the ancillary service system to take over and depending on the desired output power, it may shift the slave trackers e.g. by 6 pulses to the east and then transfer the control again to the existing tracking system. It may take over control again in the same manner, in case it detects wrong output power. The reason for that system's attitude is the flexibility potential: For example it can easily reduce the energy production more if requested. So the processor can always adjust the output power compared to the power that could be produced.

A very important aspect of the control algorithm is that once the command signal for power control is detected, the system checks the integrity of the power plant. A serious functioning problem, like tracking disability grants the system authority to ignore the power drop demand. As a result, the power plant continues operating and sends a message for execution disability. The most serious problem that the system must check is whether a pilot tracker can work properly or not, since this tracker is used to calculate the actual power that can be produced. If a fault is detected, the system terminates the reduced power mode. Except from the pilot tracker, the proposed system checks also the other trackers. It is necessary to ensure that all the trackers work properly. If one tracker has a problem following the pilot base commands, then the system ignores inverters production of the damaged tracker and lets the other slave tracker to follow the master tracker.

In order to realize the above integrity operations, the following recording indications are needed. First of all, power production of the pilot tracker's inverter is recorded. Then a second meter measures the controlled decreased power production of the other trackers' inverters. Finally, a third measuring device records the total power delivered from the power plant. This way, the power and energy that should have been delivered to the network is calculated. Finally, a device that collects the inverters' output data is created. So the system has the advantage of online detailed monitoring. The authors' purpose is to adapt the system to all existing trackers, the majority of which are controlled by PLC using a time algorithm or sensors.

In this case, the great challenge is to take control of the existed tracking systems without changing them, so that the cost will not be increased enough. The idea is to apply a parallel system which will take control when necessary. The step-by-step procedure is as follows: First the outputs from the PLC system that drive the slave trackers are isolated and a movement towards the direction of the desired energy reduction or increase is activated. Moreover, any sensor used by the existing system to control trackers movement is isolated. So the slave trackers now have their new control system. The system checks every tracker input. It measures output power of master inverter and it compares it with the slaves trackers production. So it controls movement to achieve power drop up to the desired price. The proposed system controls the slave trackers until a new command to deactivate the power reduction process is received. Once such a command has been sent, the proposed system shifts the trackers to the same position as the master tracker, by sending to the PLC virtual input signals. For example, if the position of the master and the slave trackers are controlled

originally by a sensor, the ancillary services system supplies the pulses that the PLC should have obtained in that coordinates.

In Fig. 1, the block-diagram of the control algorithm is described, whereas in Fig. 2, the block diagrams of the board and its connection to the existing sun-tracking system are presented. In Fig. 2a, the EXTRN System is the external unit that communicates with the power network administrator (DSO) through ripple control. In Fig. 3, a photograph of the system is shown. In the centre of the board, the microprocessor that regulates the movement of the trackers is located. The LED lights at the upper part indicate the data input and the LED lights at the right-hand side indicate the outputs to the existing PLC system of the PV plant.

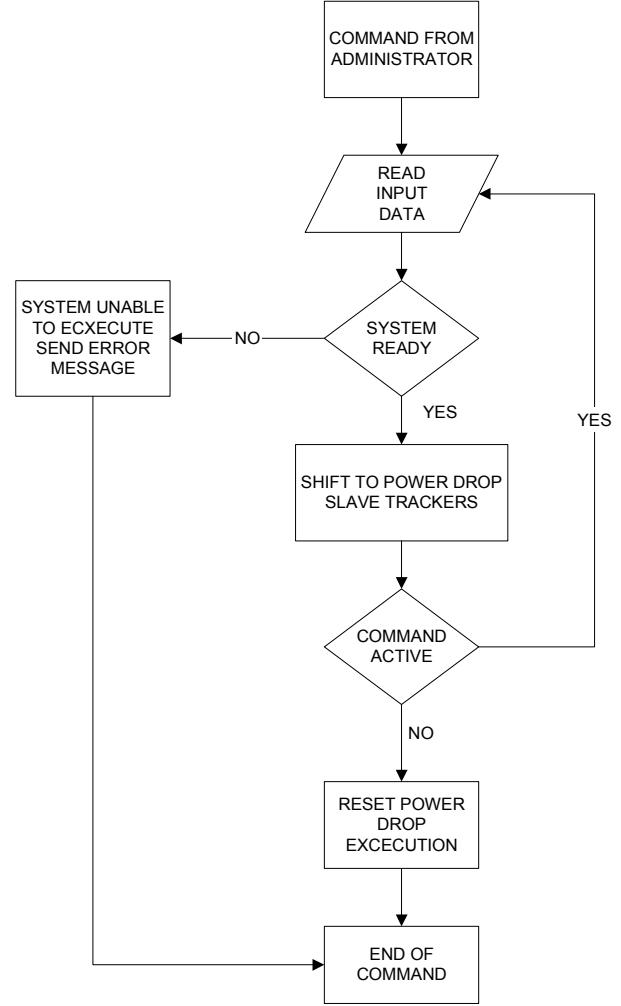


Fig. 1. The algorithm block diagram.

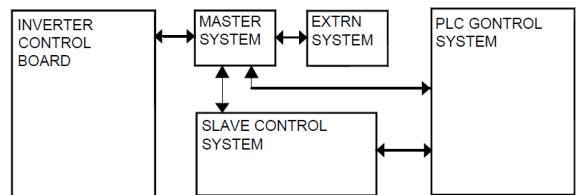
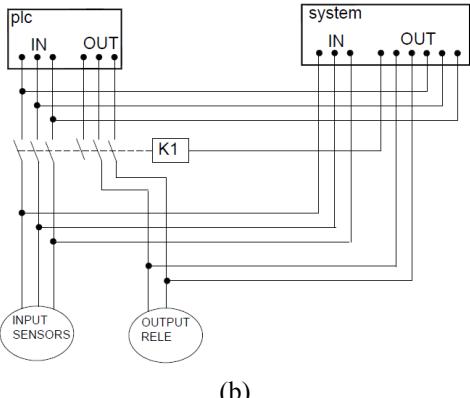


Fig. 2 (a)



(b)

Fig. 2. (a) The block diagram of the modules of the proposed control system, (b) The block diagram of the connection of the board to the sun-tracking system. The transfer of control between the two systems is obvious



Fig. 3. Photograph of the modules and boards

2.2. Cost analysis

The authors' system is not expensive. It is designed to be installed in parallel to the existing control system. It needs extra power measuring systems for each inverter which is on board at the proposed system, except from the current and voltage sensors. The readings of the inputs and outputs of the existing control system are acquired through mini relays, to achieve isolation. These mini relays do not allow the input data to reach the PLC and do not allow the output command of the PLC to reach the slave tracker. So only the proposed system receives the slave tracker input data, in order to control the slaves behavior and isolates the PLC output. The most expensive part is the command board and the transceiver that is used to communicate with the Distribution System Operator through the ripple control telegraph, which sends signals through power lines to specified parts of the network. In this paper, the commands are

transmitted by utilizing ripple control and an Internet connection. However, the cost reduces significantly if the signal is transmitted to the PV plant through the newly introduced DAB energy data communication protocol [9-11], that is described in more detail in the following section.

3. 3. Communication system based on DAB and existing smart metering infrastructure for the transmission of the commands to the PV-ancillary system

Digital Audio Broadcasting (DAB) is seen as the replacement for the outdated FM radio broadcasting in many European countries. It is well established and allows transmitting arbitrary data alongside audio programs and is especially suited to address small electric loads for demand response and DG units for supplying ancillary services. This technological approach is so far unique and enables new, innovative business models. Due to the cost effectiveness of this technology and the already existing infrastructure, small electric loads can be utilized for demand response, PV units for supplying fast ancillary services to the grid and prosumers for increasing self-consumption, which otherwise could not be integrated economically.

The main idea involves the attachment of a DAB receiver to electric devices (from small household appliances up to EVs and PV units) in order to enable DAB-based switching of electric loads and DGs. As a second step, to have the manufacturers of the devices integrate a receiver already in the factory. This integration can involve also several DAB services, from which the user picks one using displays and controls on the devices. The nature of DAB as a uni-directional communication standard naturally ensures the protection of users' privacy rights and data protection. There are no further regulatory constraints concerning the frequencies used for the DAB broadcast, as the data is sent within a multiplex with an already existing broadcasting license. Regarding DAB standard and its availability in Europe, in many countries regular service is provided while in the rest, DAB is in the phase of final trials or implementation, as shown in Fig. 4. DAB is mostly transmitted in Band III (174-240 MHz) and can transport arbitrary digital data in parallel to the live audio stream. The protocol is based on several layers, the lowest ones containing error-correction coding and an orthogonal frequency-division multiplexing (OFDM) modulation. On the higher levels, data can be transported in the fast information data channel (FIDC), which is done already for traffic data and emergency warning system data or it can be transported in the main service channel (MSC). On the broadcasting operator's side, multiplexing is done to combine several audio and data streams into a single data stream. On the receiver side, several commercial DAB baseband receivers are available offering DAB reception on a single IC. DAB receivers exist that combine DAB, FM-radio (including RDS decoding) and WLAN on a single chip. Stand-alone DAB processors can further directly connect to digital displays and device's control keys. Signal decoding can be done on-chip and output through the serial peripheral interface (SPI) or universal asynchronous receiver transmitter (UART) standard. The bitrate of a multiplex can vary, but a typical value for the UK is 1,184 kbit/s.).

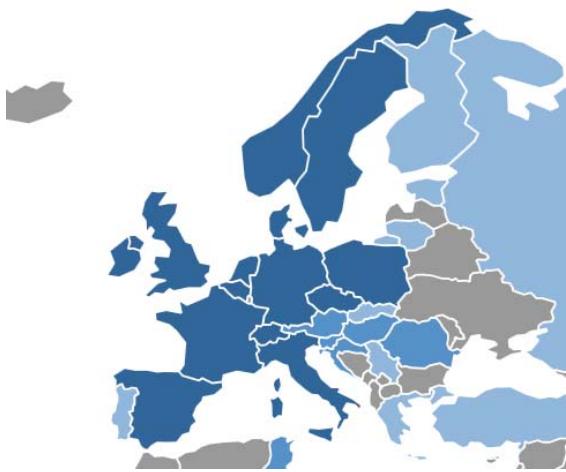


Fig. 4. DAB broadcasting countries: (i) dark blue color: full-scale roll-out with close to 80-100% coverage of private households in the coming years, (ii) blue color: coverage of up to 50% and expectations to switch to DAB in the coming years, (iii) light blue color: trials and services or have plans to switch

The advantages of using unidirectional DAB signalling are the following:

- ✓ DAB is one of the cheapest technologies as it exploits synergies with radio programs, has very cheap and established infrastructure costs as well as inexpensive receiver technology, and this maximizes the total load which can be exploited for demand response. A large city can be connected with a single antenna; for example, compare GSM with 1000 antennas for Berlin vs. 1 antenna for DAB vs. 1 million routers/home WLAN installations for WLAN connectivity.
- ✓ It is the most promising technology for applying emergency grid stability actions, since it reaches simultaneously to a great number of appliances with minimum time delays.
- ✓ It has very good reliability; it has emergency battery supply in the case of a blackout which is much more robust than other technologies.
- ✓ It can be easily integrated into existing devices/appliances. Therefore, a much larger market can be addressed.
- ✓ There are no privacy/data protection issues.
- ✓ There is reception in buildings and outside.
- ✓ It is one of the few demand response technologies that can be easily attached to special loads, like pumps used in agriculture, etc.
- ✓ In a final solution, the DAB receivers are integrated into the appliances by the manufacturer already, bearing also a “DR-enabling label” in analogy to the “EU energy label” for devices which support this feature.

The first, necessary step towards the realization of the new technology is the development of a DAB communication protocol that will enable the functionalities of the smart buildings and of the smart electricity grids. The potential of smallest household loads for demand response, prosumers and PV plants is enormous and of the order of billions in Europe. The requirements of such a protocol (DAB+) are described in an accompanying paper of this conference.

A main concern of the application of the DAB+ protocol to the electricity grid devices is the back-channel information flow from the loads, prosumers and PV installation to the DSOs or energy providers. This should be achieved through the smart metering infrastructure and is possible, since DAB+ receivers are supposed to be installed to smart meters as well. Thus, the smart meter will send data back to the DSOs and energy providers on-demand, i.e. only when it receives the DAB signal to do so, e.g. after an emergency request for reducing the output power of a PV installation or for switching on or off or dimming loads, or when it receives a signal for DSM policy application, etc. This way, data transfer congestion is avoided and an immediate feedback, of which PV installations or loads responded, is available. The adjustment of the DAB receivers even to existing smart meters is possible, since DAB extension boards and interfaces to other protocols (MODBUS, etc) are already available [11].

4. PV plant with sun-tracking system for testing

The proposed system has been tested on many types of trackers. The biggest difficulties to apply the idea appeared with trackers where the movement is controlled by linear gearbox. For the needs of this paper, the system was installed in a power plant which has five trackers with installed power of 20 kW each. The construction of each tracker is as follows: The panels on idle mode are in the direction north to south and are located in relation to the level of ground, on a slope of 20°. Six panels are grouped together on a frame. 14 of those frames constitute one tracker. Each frame is mounted on a metal shaft part of the tracker which can perform a semi-circular motion in the East-West direction. Each bracket of the frame is held in a linear axis. Each tracker has the same number of panels and therefore the same installed capacity. In summary, there are 5 same trackers that are running the same route in one common PV power plant. Therefore, by measuring the output power of 1 tracker, the output power of all trackers is assumed to be the same. This single pilot tracker is used as reference point, to calculate the output power that the slave trackers should obtain. Based on these assumptions, the authors' system then calculates and controls the power that is produced by the power plant. In Figs 5 and 6 the photographs of the pilot PV plant and of the installed boards are shown respectively. In Fig. 5, the photograph is taken during the ancillary service operation and it is obvious that the slave trackers (rear) have different angle than the master tracker (front).



Fig. 5. The pilot PV plant



Fig. 6. Photograph of the board next to the PLC cabinet of the pilot sun-tracking system

5. Experimental Results

In most of the sun-tracking systems, a single base follows the sun optimally. In the proposed system, after receiving a command for power change, this single base keeps following the sun optimally, whereas the others are turning to the east in such a relative angle to the master-tracker base, that the plant can achieve the desired power production. This control system is also important, in order to calculate the lost energy. In Fig 7, two typical PV power production curves of the pilot installation are shown, after applying a command for 10 % of power reduction. The dotted line is the actual power production and the continuous line is the calculated output power that should have been produced, if no ancillary service was applied.

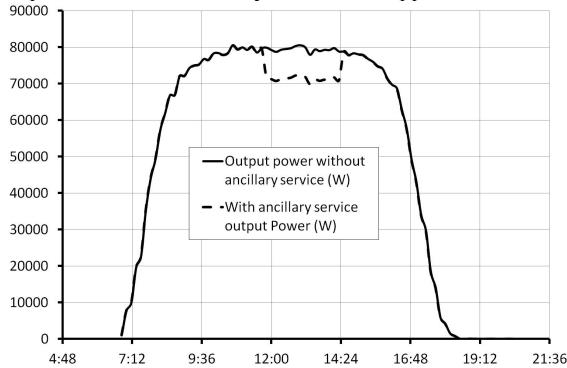


Fig. 7. Power curves for operation of the pilot PV plant, after a command for 10 % of power reduction.

6. Conclusions

In this paper, an innovative, cost-effective and easy to install technology is introduced that allows PV sun-tracking systems to regulate their production according to the demand. The main idea is to use the sun-tracking system, i.e. by changing the position of slave trackers, for achieving not the maximum possible power output but the desired one. The proposed system is also able to calculate the maximum power and measure the lost power, therefore enabling charging and market integration potential. The system can be adjusted to almost all sun-tracking systems, whereas the signal transmission towards the PV system can be accomplished by the newly-introduced in this paper Digital Audio Broadcasting (DAB) energy data transmission

protocol. The proposed system is applied on a 100 kW-installed capacity PV power plant. The results show that the desired power regulation can be achieved with great accuracy and with minimum time delay. The described procedure, not only reliefs the local distribution grid from the strain during peak production periods, but can also contribute to cost-effective operation of the grid. Moreover, it can also contribute to increased penetration of PV power plants in a single area, since it regulates energy peaks from RES.

7. References

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