Monitoring and control of distributed power generation systems such as photovoltaic system

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Abstract

In this paper an idea of a monitoring and control system for renewable sources is presented. A brief description of an working configuration was made and a two level control for it was proposed. Low level device handles proper operation of solar panels array connected to the grid and energy storage device through power converters. This includes tracking of the MPP point for optimal working conditions using modified perturb and observe algorithm. Higher level device handles communication with transmission system operators, presents visualization of the power flow and chooses power generation strategy. It's based on IEC 61400-25 standard for communication with distributed energy sources. This device also integrates several power sources in the area and it's using modbus rtu and tcp protocols.

1. Introduction

The structure of power generation systems needs changes. In near future most commonly used fossil fuels will become more and more expensive as easily accessible sources are going to end. The alternative is to use renewable sources such as solar energy, wind power, biomass, and in limited range nuclear power [4]. Also the new regulations concerning environmental protection and CO_2 emission limits are making even more demand for installing more renewable power. However as more distributed power sources are being connected into the electrical power supply system, there is urgent need for methods of efficient and reliable monitoring and control for such sources. This paper presents an idea of controlling photovoltaic power source connected to a small system with energy storage and conversion devices. It can be used as a part of microgrid or connected directly to the electrical power supply system.

2. Controlled object description

Generated power by most of the renewable sources largely varies in time (fig. 2). However the electrical power supply system expects them to provide constant and earlier declared power to maintain the quality of the distributed energy. In case of solar panels generated power depends on irradiation, temperature and shadowing conditions (L 5). If large number of the same source type is installed on relatively small area, generated power varies a lot, including shortage and overpower conditions. To overcome that, the device configuration (fig. 1) was suggested. The designed control system will be able to provide optimal usage of generated power by the solar panels array and secure connection to the grid.
Usage of energy storage device utilized mostly in peak hours reduces prices of energy distribution and also reduces needed reserves of power installed in the area [4].

Usually DC/DC converter keeps optimal output voltage to provide best possible usage of solar panels, which means they work in MPP point. The range of voltage changes is limited by the input range of DC/AC converter. However if more power is requested from the system than produced by photovoltaic array, the shortage is covered by energy storage (fig 2). The figure shows real power changes generated by small photovoltaic array installed at the Warsaw University Of Technology. Area below the line shows moments where less power is generated than used.
Proper operation of energy storage is maintained by an intelligent rectifier [3] working between peak hours, when energy is less expensive.
More information relating to this whole system is provided in [1].

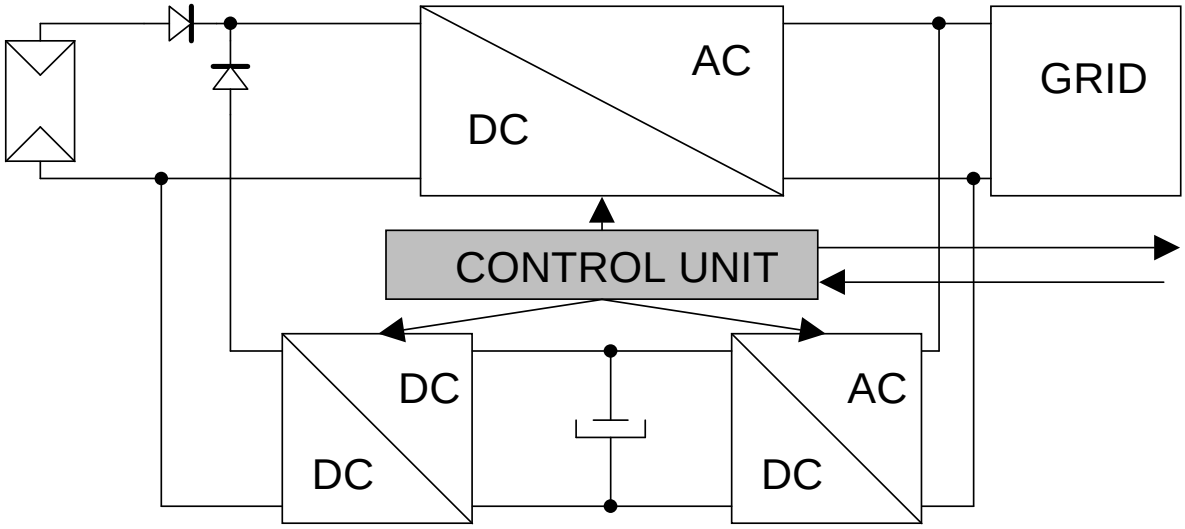

Fig 1. Suggested device configuration including energy storage device

3. Controlling photovoltaic power source

In order to maximize power generated by solar panels proper working point should be maintained. It's called MPP which stands for maximum power point (fig. 3). This point is unique for each solar panel or array and moves as irradiation changes. That's why to keep optimal working conditions for solar panels a dynamic tracking algorithm (MPPT) should be implemented. By changing out voltage of a DC/DC converter solar panels working point may be adjusted to MPP in every moment making it less depend on environmental conditions.

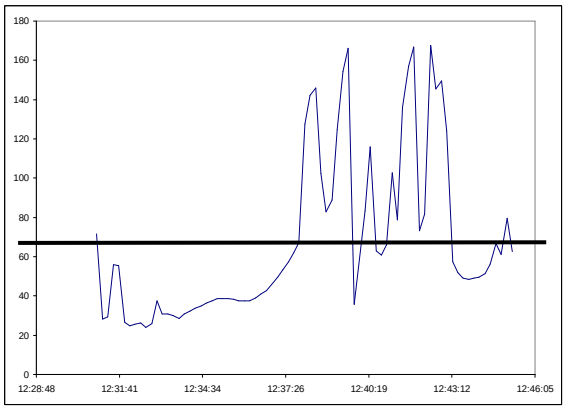

Fig 2. Power generated by a real photovoltaic system at 20 minutes period

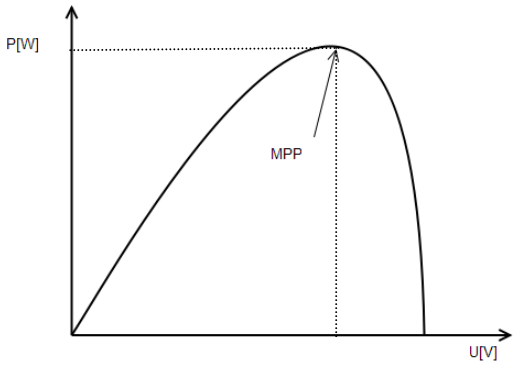

Fig 3. MPP point

A device based on Philips LPC2138 microcontroller was build to provide monitoring and control of DC/DC converter. In measures solar panels current and voltage. Based on the these values one of the MPP tracking algorithm is used. Output value made by algorithm is used as an input for PI voltage regulator used for controlling DC/DC converter. This process makes it possible to maintain optimal conditions for photovoltaic array and properly use of energy storage. At the same time this device may be controlled by outside master controller to provide proper behavior of the source in emergency situations, i.e. feed all stored energy to the grid or turn off solar panels by rising voltage. Such usage greatly increases reliability of the whole system connected to the grid. Access to all device registers is provided by the serial RS232 or RS485 line and it's based on MODBUS RTU protocol, which is one of the world leading industry communication protocols. This connection includes monitoring of all measured signals, and ability to change device behavior. Usage of MODBUS protocols offers an opportunity to easily integrate designed device with already installed systems, particularly master monitoring and control devices.

4. MPP tracking algorithms

There are several MPP tracking algorithms, however these are most popular solutions [5]

- Perturb and Observe (P&O)
- Incremental Conductance (INC)
- Constant Voltage (CV)

Most commonly used algorithm is P&O because it's easy to implement in target system. It was used as a base in study of designed system. During it's operation, voltage is constantly adjusted in small steps and the reaction of the system power is observed. If power is rising voltage keeps changing in the same direction. If power drops after voltage adjustment was made direction of changes is reversed.

This algorithm usually works very well in constant or low speed varying conditions, but it's weakness may be observed when rapid irradiation changes happens or solar panels are partially shadowed.

Different approach is taken in constant voltage algorithm. It's based on an assumption that MPP stays in constant dependence with solar panel's open circuit voltage (V_{0C}). It's assumed that 0,76 ratio of V_{MPP}/V_{0C} fits most of the solar panels [5]. To measure V_{0C} DC/DC converter rises voltage high enough to drop the panel's current to 0. This algorithm doesn't give optimal results and wastes some power in times when V_{0C} is measured. However combining this algorithm with P&O may give some advantages like a starting point for P&O algorithm near real MPP point.

Another modification to P&O algorithm made for better performance is to wait some time after perturbation was made. Algorithm waits as several measurements indicate that new current value is stable enough. This provides protection for rapid irradiation changes that confuses P&O algorithm.

5. Modeling the system

The simulation was a first phase of the research. The idea and algorithms were modeled and proven that they are working. The simulation results may be found in [2].

The next step was to build a model of the whole system. It was build from several dc/dc converters with different regulators to simulate devices such as solar panels and constant load.

All this devices were connected to a microcontroller with modified P&O algorithm working. It was possible to alter different parameters of the software by connecting to microcontroller with modbus capable application using serial link. This included starting and stopping P&O algorithm, changing step range and step time, range of work, dead area, changing PI voltage controller parameters and manual control of a output voltage.

Early investigation gave some interesting results. Although P&O algorithm seems to work it's also very unstable and needs some more tweaking. However in limited range it was working and tracking MPP. More study of this conception is needed for proper stable behavior.

After building fully working model connection to the real photovoltaic system is planned.

6. Monitoring and control of large number of power sources

When using microcontrollers connected with different DC/DC converters new opportunities may be taken. It's possible to build independent supply system that fulfills tasks from transmission system operators. Utilization of renewable sources in large scale, such as in Germany [6] demands new methods of monitoring and control for each power source to achieve realization of power generation forecasts. To achieve this in a convenient way it was decided to design and build a device that interconnects local generators and systems operators.

Such device would be designed according to IEC 61400-25 standard, which may be treated as reference in terms of connecting renewable sources. This standard is extensively analyzed in [7].

Basic functions of the designed device would be:

- gathering data from slave devices, usually power converters controllers
- sharing some of the information in the network, through web browser and dedicated application
- providing access control for the power devices
- storage of archive data for later analysis
- ability to easy alter it's configuration
- controlling power flows between different power sources and the grid to always use most inexpensive and efficient power source available in controlled area

7. Designed device

Analysis of those requirements showed that most convenient device for such task is a simple, yet powerful microcontroller which can handle some operating system. It was decided to use ATMEL AT91RM9200 microcontroller based on ARM 9 architecture. The development board used had 64MB of ram memory and 16MB o flash based memory. It was enough to run Linux for embedded devices as an operating system. This was a solid base for specialized software made to handle all the tasks. Usage of an already configured operating system greatly reduces development time and allows more futures in the final device. Outside of the system designed device is connected by the Ethernet.

Visualization access from the Internet is handled by integrated web server that dynamically generates web pages. To get more control of the system an dedicated application is needed. It will use MODBUS TCP protocol to connect to the device by TCP/IP.

From the inside of the system all the power controllers are connected by a RS485 or RS232 communication channels and make use of MODBUS RTU protocol. At this time author focuses on controlling single energy source such as photovoltaic system, but in the future larger number of devices would be controlled in near area, i.e. small town.

Application of Linux operating system made it very easy, to configure variety of services. Also adding more functionality to the device is a simple task, i.e. in the future different protocols may be used to access data, such as DMP-3 [7]. The archival data would be written to files on SD flash card, which makes it easy to choose storage space according to amount of written data. Also it would be possible to exchange card to new one if it's broken or full.

8. Overall conclusion

The idea of monitoring and control devices for photovoltaic system presented in this paper is under further investigation by the author and it's not completed yet. However it shows the direction of the taken research covering integration of the several parts into one reliable block which may be easily connected to the electrical power supply system. It was showed that there are two parts of the system. Low level controller that handles connection of a photovoltaic system to a DC/AC converter and maintains optimal operating conditions for the solar panel array. It also chooses different strategies for energy storage. All this provides reliable connection of this power source to the grid.

On the other side high level controller, which is in design, provides communication for several devices in the whole area with systems operators, chooses different strategies for energy generators and allows an easy way to monitor all the connected systems.

Using sets of those two devices will provide a full solution to integrate a distributed energy sources into the electrical power supply system and maintain reliable control of them.

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