Cloud Connected Power Inverter

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Abstract. In the Industry 4.0 paradigm, the control of electrical power production and consumption in small energy nodes remains an important objective. The new energy production nodes are usually installed in locations with reduced power requirements. They can produce energy to cover the needs of the consumer and the excess can be pushed in the national power grid system. This paper proposes a scheme to control the balance between produced energy, the locally consumed energy and the energy pushed into the national power grid system, using grid controlled inverters. The inverter connects the local energy source, with the local consumer and also ensures a bidirectional connection to the national power grid system. The inverter can be programmed to satisfy the local consumer power requirements, from the local source or from the national power grid system, and it can also deliver the local excess energy to the national power grid system. The controller is connected with the Internet and is able to send data to an IoT server. This paper presents a solution, along with its supporting technology, to create a network infrastructure based on thinger.io IoT technology. We present this solution for control, monitoring and optimization the electrical power production and consumption for small consumers using the IoT technology. This device can be used in small farm areas where we can monitor and control the balance between energy production and energy consumption from local sources or from the national power grid system. The device can also be used to monitor and control energy flow in remote small industrial plants or agricultural farms.

1. Introduction

In the latest years, as a result of rapid development of cloud computing concepts and technologies, more and more cloud-based business models and practical applications are emerging in energy production environments, including cloud energy consumption monitoring and cloud energy transport logistics. Such systems integrate the distributed resources with artificial intelligence to optimize the balance between energy production and consumption.

One important request from cloud technology is the possibility to access information from different devices (numerical controlled machines and processes, computers, notebooks, tablets or phones). The challenge is to integrate the variety of controller manufacturers with their own information accessing interfaces and security and protection data protocols.

At the present a lot of small energy producers (micro energy production farms) emerged and became familiar with traditional energy producers [1]. These energy farms are organized in small group areas and they are connected in small power grid systems, named micro grids. A micro grid can be organized to be self sustaining and automatically control the energy flow. Adopting the new cloud computing technology, micro grids will be able to communicate between them and they also will be
able to be integrated in the national power grid systems. The base unit of the micro grid is the grid connected controller.

This paper proposes a cloud grid connected controller. This controller is responsible with power flow control according with energy locally produced and the local consumer demand.

The controller connection to the Cloud is ensured using IoT (Internet of Things) technology [2]. The data is transferred into the Cloud using safe communication protocols (including data encryption and data protection). Information transferred in the Cloud can be accessed from anywhere using Internet access infrastructure for Cloud Computing. Another important aspect of using IoT and Cloud technology is the possibility to monitor, analyze and optimize energy power flow using fast decision algorithms based on artificial intelligence.

2. Smart Micro Grid Architecture

The base concept of Cloud Connected Power Inverter is related to the Smart Micro Grid. Smart Micro Grid can be implemented in isolated human communities or villages. Each house can have one or two energy production sources (wind turbine, solar panels, generator sets etc.). Because the power produced by these sources can be more than enough for the local consumer, the energy excess can be exported to the local micro grid.

![Figure 1. Micro Grid Geographic Area.](image)

If the local source is unable to ensure the power requirements of the local consumer, energy can be drawn from the local micro grid.

Figure 1 presents a scenario that include three isolated little farms. Each farm has its own energy source to ensure their electrical needs (one is powered from solar panels, the second is powered from a wind turbine generator and the last is powered from an electrical generator group). To be able to have an optimized electrical consumption between the three households all generators are connected together and used according to weather conditions. One simple solution is to bring them together with a power cable and use Cloud connected power inverters (PGC-Power Grid Connected Controller) connected in a micro grid structure (see figure 2). Each PGC connects the local power generator with the local consumer and a bidirectional electrical power line. This connection is presented in figure 2 in the power layer. From IoT cloud connection point of view, the PGC controllers are connected together in the same logical network, named Local Cloud Area. This area is controlled by an IoT Server named Local Server Controller. Electrical power transfer in this micro grid is controlled by the Local Server Controller. This server can be located physically in this network or it can be installed in the cloud. If the server is stored in the cloud then each PGC must be configured to access and communicate with the Local Server Controller. This server manages power transfer through the micro grid by controlling each PGC power inverter controller. The Local Cloud Area (see figure 2) communicate information with IoT server (located in Cloud) using IoT Gateway. This gateway is able to forward data from each PGC or through the Local Server Controller, to the IoT Server. Also the IoT Server is able to manage electrical power transfer through this micro grid by controlling the Local Server Controller.
If micro grid consumers require more power, because the local sources are not able to generate enough energy in the grid, this micro grid can be connected with the National Power Grid System. The connection is made using a special PGC, named National Power Grid Energy Connector. Also this PGC is logically connected in the Local Cloud Area. This controller manages power flow from the National Power Grid to the micro grid or from the micro grid to the National Power Grid System if the local energy production exceeds local power requirements.

3. Cloud Connected Power Invertor. PGC-Power Grid Connected Controller

3.1. PGC Architecture
PGC is the main unit that connects the local consumer with the local energy supply and the local grid area (see figure 3). This controller provides the local consumer needs with electrical power generated by the local power source or the local power source and from the grid. Also PGC will inject energy in the grid if the locally required power is less than the produced energy.

To be able to ensure this functionality the PGC must be connected with the micro grid, this connection is provided through the Local Server Controller.
Figure 4. PGC Controller.

One PGC Controller unit includes (see figure 4):

- **CSS1** – controlled synchronized switch to connect PGC with the Power Grid. This switch controls the power transferred to/from the Power Grid to our unit. The switching process is synchronized with voltage signal from the Power Grid. The controller measures and controls the current and the power flow through the switch.

- **CSS2** – controlled synchronized switch to connect local consumer with PGC. This switch controls the power transferred to consumer. The switching process is synchronized with the voltage signal from PGC. The controller measures and controls the current and the power flow to the consumer. This module also has the role of consumer protection.

- **CSS3** – controlled synchronized switch to connect local generator with PGC. This switch controls the power transferred from the local power generator. The switching process is synchronized with the voltage signal from the local generator and from the Power Grid. The controller measures and controls the current and the power transfers from the local generator. This module also has the role of generator protection.

- **PGC control unit** is responsible for controlling the power delivered through PGC and with local consumer and generator protection. This unit controls the functionality of CSS1, CSS2 and CSS3. Also, the unit can be controlled from the cloud (through IoT gateway) or from the Local Server. The unit sends the status to the Local Server or to the IoT server. PGC control unit is implemented using an STM32 microcontroller platform.

3.2. CSS. Controlled Synchronized Switch

Each Controlled Synchronized Switch (CSS) is based on STM32 microcontroller architecture (see figure 5). The module connects two electrical power circuits (one is the input circuit and the other one is the output circuit) and ensures a bidirectional power transfer between both circuits in four quadrants (U-I). This CSS protects the outputs circuit against power surges, short circuit, and under voltage. To be able to ensure these functions, the CSS controller measures the voltage in the input circuit and the current in the output circuit. Also, to control the switching circuit the CSS uses a synchronized signal that can be connected to the other source. Power switching is controlled by 2 IGBT power transistors connected in antiparallel connection, between the input circuit and the output circuit.
Each CSS controlled synchronized switch contains:

- **Q1, Q2** – two IGBT power transistors used to control the power transfer between input an output circuit. Transistors are controlled through gate control unit module (GCU) [3, 4];
- **GCU** – Gate Control Unit module is based on IX2113 IGBT gate controller ICs. The inputs are connected directly to STM32-CPU [4];
- **STM32-CPU** – main controller of the unit. The CPU is based on low cost 32 bit STM32F103C microcontroller (running at 72MHz) [5]. The controller uses the following signals:
  - **AU1** - connected to A0 – connects the input analog voltage signal to the CPU ADC unit;
  - **AI2** - connected to A1 – connects the output analog current signal to the CPU ADC unit;
  - **AZ3** - connected to A2 – connects the synchronized input analog voltage signal to the CPU ADC unit;
  - **nOFF** – connected to D4 – connects an external digital signal that enables the unit functionality (if nOFF = 1);
  - **OQ1** – connected to D9 – Q1 IGBT gate control signal;
  - **OQ2** – connected to D10 – Q2 IGBT gate control signal;
  - **OP3** – connected to D11 – the power contactor control signal. It is active if the unit is disabled or the current or power transferred through the switch exceeds the preset values;
  - **I2C communication port for connecting with PGC Control Unit**;
- **TC1** – current transformer – used for measuring the current through the power switch;
- **VD1** – voltage divider – used for measuring the input voltage applied to the power switch;

STM32-CPU unit implements the following registers:

- **SR** - Status register (RO) – This indicates the status of CSS unit;
- **U1** – Input Voltage (RO) – input voltage value;
- **U2** – Output Voltage (RO) – output voltage value;
- **I1** – Current (RO) – current value, measured through the switch;
- **P1** – Power (RO) – power transferred through the switch (if the value is positive the power is transferred from input circuit to output circuit, or if the value is negative the power is transferred from output circuit to input circuit);
- **Fi_SYNC_1** – Phase Shift (RO) – the phase shift between SYNC signal and the input voltage;
- **Fi_SYNC_2** – Phase Shift (RO) – the phase shift between SYNC signal and the signal that controls the IGBT transistors phase;
- **P2** – Power (RW) – the preset value of power transferred through the switch;
- **I2** – Current (RW) – the preset value of current transferred through the switch;
- **SW_OFF** – External Locked Status (RO) – the value of nOFF signal;
- **DISA** – Disable unit functionality (RW) – the running status of the unit;
• PROT – Protection Relay Status (RO);
• PROT_RST – Protection Relay Reset (WO) – resets the protection relay status;
• ADDR – I2C Address (RO) – get the I2C communication address;

Registers are accessed through the I2C communication layer.

3.3. PGC. Control Mode

PGC Control Unit communicates with CSS modules over I2C local network. The PGC Control Unit communicates with CSS modules (CSS1, CSS2 and CSS3) and establishes their running modes. The operating mode of PGC is set by Local Server controller. To be able to operate the PGC Control Unit uses the following registers:

• SP1 – Input Power (RW) – the power injected into the External Power Grid (if value is negative) or the power supplied by External Power Grid (if value is positive)
• P1– Power transferred with the Power Grid (RO) – the power exchanged with the Power Grid
• SP2 – Generated Power (RW) – the nominal power that can be generated by the local generator
• P2 – Generated Power (RO) – the power generated by the local source
• SP3 – Consumed Power (RW) – the nominal power that can be consumed
• P3 – Consumed Power (RO) – the nominal power consumed

The Local Server can set SP1, SP2 and SP3, for each PGC from the local energy grid, in according with area settings. The local implemented algorithm is presented in figure 6.

![Figure 6. PGC Algorithm.](image)

4. Conclusions

The research presented in this paper explores the design of an IoT Power Grid Connector controller. This device can be used to monitor and control the energy flow for small energy producers / consumers connected to the national distribution grid. The design of the PGC controller is modular and compact using low cost microcontrollers powerful enough to ensure real time computational requirements. The ability to measure and transfer data in real time and also to control the power flow remotely makes the PGC controller suitable for integrating in more complex IoT energy control systems, sustaining the process of transitioning from the old power distribution grid paradigm to the more advanced and efficient Smart Grid concept. The solution can also be used to connect multiple small consumers and producers from remote small areas that do not benefit from the national power grid connection, to form independent micro grids, in an effort to ensure optimal energy distribution to meet the power requirements of those small local consumers.

5. References

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