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OpenStrom

Technical Specification

v0.7

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Content

Overview

OpenStrom is a hardware device that can measure and control up to 10 power circuits over the internet. It is intended to monitor and control the energy parameters from the wide spectrum of home and industrial appliance.

The device should meet to specified technical requirements and to cover certain functional features.

The main features are:

Target Specs

Component	Characteristics
MCU	80 MHz 512k kB + 128 MB
Connectivity	LAN, Wifi ZigBee
Sensors	Voltage, current, mean active power, mean reactive power, voltage frequency, power factor, phase angle between voltage and current, mean apparent power 90 - 250 V AC 0 – 40A 7.4 kHz sampling
Relays (10x)	Switching up to 40A at 250V, max. 10kW
Form factor	DIN rail compatible housing (for mounting inside fuse box)

Operating temperature range: 0°C to 85°C (commercial)

Functional features

Scan, measure and record the energy parameters from 10 energy circuits that supply different types of appliances such as refrigerators, heaters, pool pumps, washers, dryers, toasters, computers and etc.

Energy parameter measurements

Active power P [W] The device measures active power up to 10 KW	P = Irms * Vrms * cos(θ); I_{ac} is a AC current in circuit; V_{ac} is voltage in circuit; cos(θ) is a phase angle between current I_{ac} and V_{ac}
Reactive power Q [VAR] The device measures reactive power up to 10 KVAR	Q = V * I * sinθ which can be positive (+ve) for inductive, negative (-Ve) for capacitive load; Q refers to the maximum value of the instantaneous power absorbed the reactive component of the load
Apparent power S [VA] The device measures apparent power up to 10 KVA	S=Vrms*Irms;
Power factor PF The Power Factor is in the range 0-1	In AC circuits, the power factor is the ratio of the real power that is used to do work and the apparent power that is supplied to the circuit.
Current and voltage [V] and [A]	The device detect and monitor the undervoltage (sag) and overvoltage (swell);
Frequency of the line Frq	

Functional requirements

- Switch 10 circuits on/off remotely via LAN or Wi-Fi up to 40A 250
- Measure data with high sampling frequency (7.8 kHz) to allow energy disaggregation algorithms for detecting of specific appliances or error states

Communication Options

- Ethernet network with 10/100 Mbit/s transfer speed
- Wi-Fi standard 802.11. b/g/n
- ZigBee standard 802.14.4

In order to meet the functional requirements, the device will include the following circuits:

- Sensor circuits
- CPU
- Relays control circuits
- Network communications
- External RAM

Technical specifications

Sensor circuits

To meet the functional features of OpenStrom the sensor system measures the current and the voltage of every electrical grid connected to the device.

The sensor circuits comprise a current and voltage sensors.

Current sensor technical specification

- The current sensor input range is - 0~40 amps AC
- The sampling frequency is 1 KHz – 7.8 KHz with tolerance +-10 %
- Output convert the analog values of current in digital sequence in 24 bits binary format
- The sensor has linear response, because small error in transformation may result in incorrect output
- Resolution of the sensor is 24-bits to be able to transform the current changes with a high accuracy
- Size of the sensor is small, because of board size limitation

Voltage sensor specification

- Voltage sensor senses AC voltage
- Input range is 0~400 VAC
- Sampling frequency is 1KHz – 7.8KHz with tolerance +-10%
- Resolution of the voltage sensor is minimum 16-bits to be able to transform the voltage changes
- Voltage spikes should have no effect on sensor components

Frequency sensor specification

Range of frequency sensor must be 45 – 70Hz. Other than, this range cannot practically achieve, because at frequency outside this range the appliance device may get damage.

Specifications for frequency design

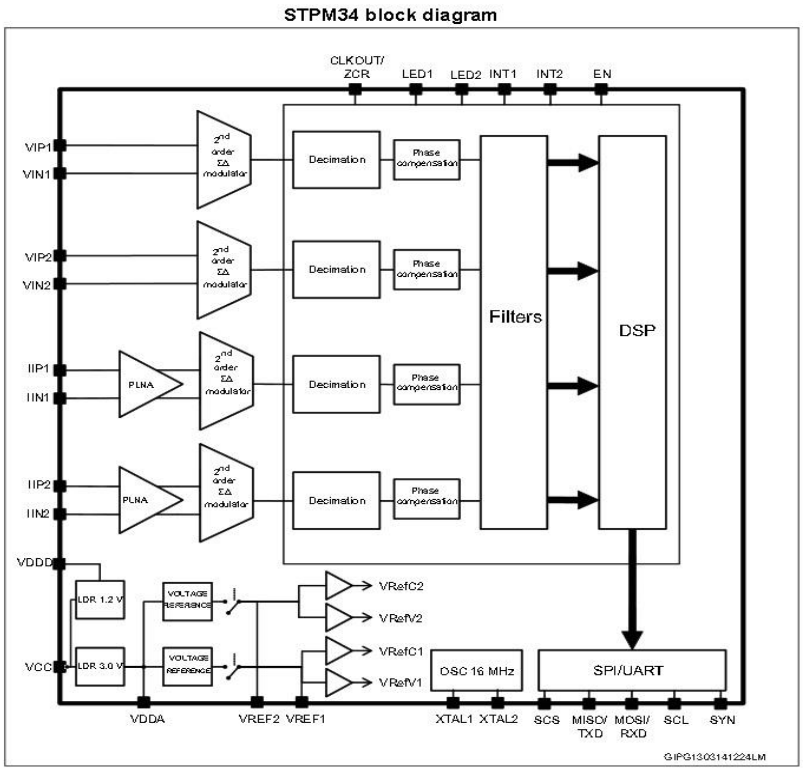
- Input range 40 – 70Hz;
- Output of the sensor will find zero crossing of input AC (important to switch relays)

Sensor circuits selection

The investigation and research of the possible sensor component implementation reached to the following solution:

STPM energy IC 34:

- Active power accuracy
  - < 0.1% error over 5000 :1 dynamic range
  - < 0.5% error over 10000:1 dynamic range
- Reactive power accuracy
  - error over 2000:1 dynamic range
- Dual mode apparent energy calculation
- Instantaneous and averaged power
- RMS and instantaneous voltage and current
- Under voltage and over voltage detection (sag and swell)
- The limits of sag and swell set up programmable
- Sampling frequency 7.8 kHz tolerance +-0.5%
- UART and SPI high-speed serial interface;
  - SPI timing specifications:
  - MCLK of SPI communication – 20MHz;
  - T_clk – Clock period - 50ns;
  - T-cpw – Clock pulse width - 25ns;
  - T_hold – Hold time - 40ns;
  - 2 independent current and voltage channels;
  - Analog input voltage specifications:
  - Current inputs voltages max +-300mV; min =-37.5mV;
  - Current channel input gain – 2, 4, 8,16;
  - Voltage inputs voltage +- 300mV;
  - Voltage channel input gain – 2;
  - Oversampling frequency – 4MHz+-1%;
  - Vcc supply range 3.3v +- 10%;
  - Supply current Icc 4mA+-400uA;
  - Input clock frequency 16MHz+-1%;



Current shunts

For the current measurements are used current shunts resistors.

The specifications for shunts are:

- Resistance rate up to 0.001 Ohms;
- Max current – 40Amps;
- Min power 1.65W;
- SMD size;

One off the more appropriate shunts covering these requirements is power metal strip resistor:
P/ N WSR2 – Vishay Co., Ltd;

Technical specifications for the CPU / Microcontroller MCU

The CPU provides the following functions:

- Acquire data from sensor's circuits
- Process data
- Send and receive data and commands from backend server through the network
- Wi-Fi, Ethernet, Zig-Bee communication interfaces
- Control the states of relay's circuits

Following the functional requirements, CPU acquires input data from current and voltage sensors of 10 grid circuits with sampling frequency between 1Hz – 7.8Mhz.

After scanning of Inputs data, the CPU exchanges the data with the backend server. At the same time the CPU control if some failures are raised (critical values of currents, voltages and mains frequency).

The high sampling frequency and the high number of the monitored and logged sensors requires from CPU to operate with very high performance and to have a large memory – RAM and flash.

A good choice would be if the CPU owns implemented network controller such a Wi-Fi, Ethernet or Zig-Bee. To be able to communicate effective with all these circuits, CPU has a high speed serial interface - SPI and UART.

We look for a CPU with a high performance, high speed serial interfaces, implemented TCP/IP stack and certain network controller.

CPU selection

We found that the PIC32MX795F512H system offers the best choice for us

Features

MCU Core
- 80MHz/105DMIPS, 32-bit MIPS M4K® Core
- USB 2.0 On-The-Go Peripheral with integrated PHY
- 10/100 Ethernet MAC with MII/RMII Interfaces
- 2 x CAN2.0b modules with 1024 buffers
- 8 Dedicated DMA Channels for USB OTG, Ethernet, and CAN
- 5 Stage pipeline, Harvard architecture
- MIPS16e mode for up to 40% smaller code size
- Single cycle multiply and hardware divide unit
- 32 x 32-bit Core Registers
- 32 x 32-bit Shadow Registers
- Fast context switch and interrupt response

MCU System Features
- 512K Flash (plus 12K boot Flash)
- 128K RAM (can execute from RAM)
- 8 Channel General Hardware DMA Controller
- Flash prefetch module with 256 Byte cache
- Lock instructions or data in cache for fast access
- Programmable vector interrupt controller

Analog Features
- Fast and Accurate 16 channel 10-bit ADC,
- Max 1 Mega sample per second at +/- 1LSB, conversion available during SLEEP & IDLE

Power Management Modes
- RUN, IDLE, and SLEEP modes
- Multiple switchable clock modes for each power mode, enables optimum power settings

Debug Features
- iFlow Trace: Non-intrusive Hardware Instruction Trace port (5 Wires)
- 8 hardware breakpoints (6 Instruction and 2 Data)
- 2 wire programming and debugging interface
- JTAG interface supporting Programming, Debugging and Boundary scan

Other MCU Features
- Fail-Safe Clock Monitor - allows safe shutdown if clock fails
- 2 Internal oscillators (8MHz & 31KHz)
- Hardware RTCC (Real-Time Clock and Calendar with Alarms)
- Watchdog Timer with separate RC oscillator
- Pin compatible with 16-bit PIC® MCUs
- Serial Communication Modules allow flexible UART/SPI/I2C™ configuration

Parameter Name	Value
Family	PIC32MX7xx
Max Speed MHz	80
Program Memory Size (KB)	512
RAM (KB)	128
Auxiliary Flash (KB)	12
Temperature Range (C)	-40 to 105
Operating Voltage Range (V)	2.3 to 3.6
DMA Channels	8
SPI™	4
I²C™ Compatible	5
USB	FS Device/Host/OTG
USB (Channels, Speed, Compliance	1,FS Device/Host/OTG,USB 2.0 OTG
CAN	2
A/D channels	16
Max A/D Resolution	10
Max A/D Sample Rate (KSPS)	1000
Input Capture	5
Output Compare/Std. PWM	5
16-bit Digital Timers	5
Parallel Port	PMP16
Comparators	2
Internal Oscillator	8 MHz, 32 kHz
I/O Pins	85
Pin Count	100

Network specifications

Connectivity

To meet the functional requirements the device transmit and receive data frames (data and commands) from/to cloud server. Therefore the communication between the device and server should be realized as communication between “client” (smart meter) and active backend “server”.

LAN transfer speed

The required LAN bandwidth depends on the amount of data collected.

Data Collected	**Bandwidth**
1 circuit at 1 kHz	
1 circuit at 5 kHz	
1 circuit at 7.8 kHz	

Network protocol

The smart meter communicates in a network using TCP/IP protocol.
The device uses DHCP protocol to get default gateway, subnet mask and IP address by default. However it is also possible to assign these values manually on the device.

Ethernet controller

The Ethernet controller as MAC structure is included in the main microcontroller. The IC 8720 realizes PHY layer as an external module.
As a output bus is used RMII (Reduce Media Independed Interface) because have better ration performance/cost.

Wi-Fi module

The device has a Wi-Fi transceiver module to communicate with an access point (router).

Wi-Fi specifications

The Wi-Fi module has the following specifications:

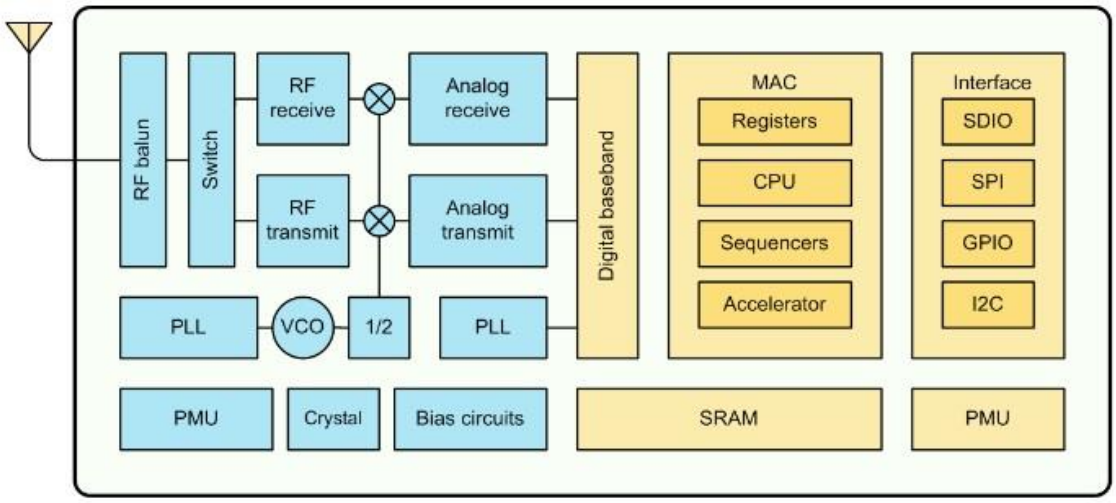
- Wi-Fi standard IEEE 802.11 b/g/n;
- Wireless transmission rate – 100Mbps, 54Mbps, 10 Mbps;
- Frequency range – 2.4 GHz;
- Functional mode – Client/AP/Router;
- Wireless security – WPA/WPA2;

- Covered distance – 100m;

As Wi-Fi controller the ESP 8266 has been selected. This Wi-Fi module meets entirely the technical specifications. Moreover, this module has very good ratio performance/cost.

Technical specification of ESP 8266 module:

Espressif Systems' Smart Connectivity Platform (ESCP) is a set of high performance, high integration wireless SOCs, designed for space and power constrained mobile platform designers. It provides unsurpassed ability to embed WiFi capabilities within other systems, or to function as a standalone application, with the lowest cost, and minimal space requirement.



ESP8266EX offers a complete and self-contained WiFi networking solution; it can be used to host the application or to offload WiFi networking functions from another application processor.
When ESP8266EX hosts the application, it boots up directly from an external flash. In has integrated cache to improve the performance of the system in such applications.
Alternately, serving as a WiFi adapter, wireless internet access can be added to any micro controller-
based design with simple connectivity (SPI/SDIO or I2C/UART interface).
ESP8266EX is among the most integrated WiFi chip in the industry; it integrates the antenna switches, RF balun, power amplifier, low noise receive amplifier, filters, power management modules, it requires minimal external circuitry, and the entire solution, including front-end module, is designed to occupy minimal PCB area.
ESP8266EX also integrates an enhanced version of Tensilica's L106 Diamond series 32-bit processor, with on-chip SRAM, besides the WiFi functionalities. ESP8266EX is often integrated with external sensors and other application specific devices through its GPIOs; sample codes for such applications are provided in the software development kit (SDK)

Features

- 802.11 b/g/n
- Integrated low power 32-bit MCU
- Integrated 10-bit ADC
- Integrated TCP/IP protocol stack
- Integrated TR switch, balun, LNA, power amplifier and matching network
- Integrated PLL, regulators, and power management units
- Supports antenna diversity
- WiFi 2.4 GHz, support WPA/WPA2
- Support STA/AP/STA+AP operation modes
- Support Smart Link Function for both Android and iOS devices
- SDIO 2.0, (H) SPI, UART, I2C, I2S, IR Remote Control, PWM, GPIO
- STBC, 1x1 MIMO, 2x1 MIMO
- A-MPDU & A-MSDU aggregation & 0.4s guard interval
- Deep sleep power <10uA, Power down leakage current < 5uA
- Wake up and transmit packets in < 2ms
- Standby power consumption of < 1.0mW (DTIM3)
- +20 dBm output power in 802.11b mode
- Operating temperature range -40C ~ 125C
- FCC, CE, TELEC, WiFi Alliance, and SRRC certified

Relay circuits

The device has 10 relays that control the state of the circuits. GPIO will turn on and off the relays. Each relay switches the grid circuit with the max load of 40 amps. The relays are mounted on the board. They are reconfigurable. The user can configure if NO or NC leads to be connected to the controlled circuit.

They have optoisolated circuits with LED indication for the state of every relay. They can provide about 100,000 clicks before which it will get degraded.

Specification for the switching relays

- Power requirements of the coil - 5v/40mA
- Can support load up to 40 A
- 10 years expected lifetime
- Contact system – SPDT with external possibility to exchange the NO with NC contacts
- Reconfigurable leads

The relays that can meet these specifications are:
JQX-16F manufacturer YUEQING HENGWEI ELECTRONICS CO.,LTD

Additional components

The device includes the following active and passive components:

- Power supply IC
- NPN transistors
- opt couplers
- Diodes
- Capacitors
- Resistors
- Quartz resonators
- Terminal blocks
- Network connector RJ-45
- 128 MB SRAM
- Battery
- Power switch

Power Supply

A 5v and a 3.3v supply will be used to provide necessary voltages for all circuits and components of device. The power supplies are step-down switching regulators located on the main board.

Power Supply 3.3 v

Rating is 3.3v+- 0.3v @ 500 mA;
Expected life time of 10 years

Power Supply 5 v

Rating is 5v +- 0.4v @ 1 Amps
Expected life time of 10 years

PCB

The device is designed on four- layers PCB.
The PCB will be designed according to EMI and RoHS requirements and will cover the following specifications:

- Core Material should be - FR4
- Copper layers – weight (oz)- 2; thickness(inch) – 0,0014;
- Thermal pads and vias for high density IC packages;
- The high frequency signals are routed without loops and max shorted;
- The digital and analog grounds are separated;
- The zones of PCB where high EMI radiation is expected should be hatched with appropriate segments;

BOM

#	Description	Manufacturer	Part Number	Package	Amount	Cost $ (@1000)	Total
1	PIC32MX512 microcontroler	Microchip	PIC32MX795F512H	64QFN	1	$6,68	$6,68
2	Energy IC STPM34	ST Microelectronics	SSTPM34TR	32 QFN	5	$1,13	$5,65
3	WiFi IC ESP8266	Shenzhen Guangshun Electronic Business	ESP 8266		1	$2,34	$2,34
4	PHY IC LAN 8720	Microchip	LAN 8720	24 QNF	1	$0,95	$0,95
5	ZigBee IC AT86RF233	ATMEL	AT86RF233	32 QN2	1	$3,39	$3,39
6	Serial RAM 128 MB	macronix International Ltd	MX25L12845EMI-10G	8-WSON	1	$1,82	$1,82
8	Terminal Blocks	Shenzhen Sced Electronics Co Ltd	TB13000-00-C		10	$0,25	$2,50
9	Ethernet Transformer	BEL	S558-5999		1	$1,27	$1,27
10	Power Supply IC	ON Semi	LM2575	5 Lead TO-220	2	$0,90	$1,80
11	Crystal oscillator 40Mhz	China manfufacturer	HC-49S		2	$0,25	$0,50
12	JQX-16F relay 250VAC/40A	Yueqing HengweiElectronics Co.,Ltd	JQX-16F(T91)		1	$0,32	$0,32
13	RJ-45 8px8c modulare jack	China manufacturer	P88RE50V2GN		1	$0,25	$0,25
14	Optocouplers 4N25	Vishay China analog	4N25	DIL-6	10	$0,02	$0,20
15	Transistors NPN	Fairchild	MMBT2222		10	$0,02	$0,20
16	*PCB*	*TBD*		*single side*	*1*	*$3,00*	*$3,00*
17	*Custom Housing*	*TBD*			*1*	*$5,00*	*$5,00*
19	Battery plus Holder?	MPD	BC501SM		1	$0,50	$0,50
20	Power Switch	ningbo	MTS 101	miniature toggle switch	1	$0,18	$0,18
21	LED	longhua	quarter watt led blue color				
22	Current transformer	Coilcraft	CST2010	custom SMD	10	$.9	$9,00
24	Filter-Bulon2450FB1	Johanson	AS222-92	custom SMD	1	$0.5	$0,50
25	RF-SwitchAS222-92	Skyworks Solution	AS222-92	custom SMD	0.35	$0.35	$0,35

The most up to date BOM is available online: https://docs.google.com/spreadsheets/d/1HDGjBxVw-1nGk1cR228rhcC5lW-j-Xv8pPq2h0ZrsOU/edit?usp=sharing

Software specification

This section determines the specifications to the software allowing the device to realize its functional features.

The software includes:

- Firmware structure
- User application firmware
- Provisioning (initial setup)
- Server application software backend

Firmware specifications

The device firmware is created with MPLAB Harmony, a development framework containing a wide set of firmware libraries (API), device drivers, middleware and application software.

To cover the basic software feature the firmware is separated in appropriate software modules, realized with the resources of Harmony:

Firmware Feature	**Harmony Resources**
Scan and measure sensors Relay control	SPI Library Module Port Peripheral Library(PLIB)
WiFi transfer	UART Library Module
Ethernet Transfer	TCP/IP Stack Module
Service functions and archive in EEPROM	SPI Library Module

Scan and Measure Sensors – SPI Library Module

This library provides an interface to manage the SPI of PIC32MX microcontroller and includes the following functions:

- System Interaction Functions – provides system module interface, device initialization, reinitialization, task and status functions
- Client Setup Functions – provides open, close, status and setup functions;
- Data Transfer Functions – provides send and receive data messages;
- Relay Control - Port Peripheral Library(PLIB)

This library provides an API to the GPIO of PIC32MX and includes the following functions:

- Port functions – performs port access read/write/toggle/clean interface to the available ports in MPU;

Wi-Fi Transfer – UART Library Module

The Wi-Fi transfer between MCU and ESP 8266 wi-fi module is realized by UART Library(API)

This library includes the following functions:

- Baud rate generator Function – provides setup and configuration interface routine;
- Transmit Function – provides setup, data transfer, error and status interface routines for the transmitter
- Receive Function – provides setup, data transfer, error and status interface routines for the receiver;

Ethernet Transfer – TCP/IP Stack Device Driver Library

This driver includes the following API functions:

- Client Level Functions - DRV_ETHMAC_PIC32Open, DRV_ETHMAC_PIC32Close, DRV_ETHMAC_PIC32MACSetup to support the TCP/IP Stack
- Receive Functions
- Transmit Functions
- Event Functions

Host Driver

The host driver performs the communication services between Wi-Fi module and AP (access point). The host driver sends request to the AP and receives the responses from the server. This driver is located in ESP8266 and can be configured and update with the appropriate software tool.

Technical specifications of Host driver

- support Wi-Fi subsystem services (callback functions);
- support asynchronous even handling;
- support hardware function of the its own 32-bit microcontroller;
- support the following peripheral interfaces:
- SPI with SCLK up to 20 Mbps;
- Standard UART with up to 3 Mbps;

User Application Firmware

The application firmware contains the following modules

- Init Routine – this routine utilizes API library function to initialize device hardware
- Input Scan Routine - this routine performs scanning and measuring inputs of energy metering IC and store there values in microcontroller SRAM
- Time Sampling Routine – this routine use timer's resources of microcontroller to generate time sampling sequences

- JSON Convertor Routine– this routine converts measured data into JSON string format;
- Switch Relay Routine - this routine provide relay's switching process
- Main program – this program should be as a state machine program to run the all firmware tasks in the device

Provisioning (Initial Setup)

The smart meter can communicate in wireless network as a standalone device (station), or as a AP (Access point) device. The selection of the ESP8266 Wi-Fi module gives two options of Wi-Fi configurations (Initial Setup):

1. Smart meter as a station. In this configuration it communicates with separated AP device (router). In this case, the SSDI and password set up by AT Command programming interface using a software tool.

2. Smart meter as AP device. In this case configuration is realized by AP control firmware. This firmware allows the user to connect to the smart meter and set SSDI and password of the network the smart meter will be connected to.

The AP firmware has the following specifications:

- set the smart meter to AP mode
- set a name and password
- present a server asking for SSDI and password
- connect to the network

Server Software

The data from the sensors will be converted into interchange formats such as JSON and XML/Webservices and send to a backend server.

The JSON format meets the requirements of the standard ECMA 404.
Since the transformation of binary data into JSON format data, increase JSON files with 33%, the software of SM should have compression algorithm such a gziped+hpack and an additional temporary SRAM to store JSON data blocks before to be transferred to the backend server.
Take into account that 10 KHz sampling creates data blocks of 2 MB per minute and requires optimization.

A SRAM buffer and battery will keep unsend data in case of connectivity or power loss and resend data to backend server after connectivity/power is restored.

Firmware functionality

For the prototype the initial version of the firmware should covers these basic features for demonstration and testing:

- Data logging of all sensor data in a XML package
- Sending the XML package to a web service backend (backend will be simulated with hyper terminal)
- Connecting to default wifi hotspot
- Connecting to LAN (DHCP)
- Controlling relays (=data package response turns on/off specific relay)
- Controlling one Zigbee device (turn on and off)

The initial firmware will only be used to show the circuit works in general. A more advanced firmware will be specified and implemented later

Housing

The housing should fit into a standard fuse box and be DIN rail mountable.

- The enclosure provides a degree of protection to personnel against access to hazardous parts and to provide a degree of protection of the equipment inside the enclosure against ingress of solid foreign objects;
- The enclosure covers the requirements of the IEC 60950-1 standard.
- The device has protection against RF&EMF radiations.
- The device enclosure has thermal shield which has sink up to 12-15W.

It should provide location of one PCB board with following sizes:

- Length - 240+35mm;
- Width - 175+35mm;
- Height - 80+20mm;

Self-testing and diagnostic possibilities

The device will execute test procedure verifying its main blocks of the device.
This procedure starts by the command from the server and generates feedback messages that determine the faults. The faults messages will be organized as a dictionary of faults.

The other diagnostic specifications are

- Watchdog timer;
- Calibration procedure for inputs sensors group;
- Check procedure for Wi-Fi transfer;
- Check procedure for relays;
- Test points (TP) at the every one functional circuit.

Safety & Compliance Marking

The device will be marked with the applicable safety and compliance marks required for commercial distribution in US and EU markets.

Specifically:

- CE
- FCC
- RoHS

In addition each device will be marked as follows:

OpenStrom a product of OpenStrom KG
Part Number P/N: xxxxxxxxxx
Serial Number: xxxxxxxxxxxxxxx
Wifi MAC: xxxxxxxxxxxxxxx
LAN MAC: xxxxxxxxxxxxxxx
Barcode

Safety Requirements and Specifications

The following are the product safety compliance regulations are implemented:

- UL60950-1/CSA 60950-1 (USA / Canada)
- EN60950-1 (Europe)
- IEC60950-1 (International)

Specifications of Safety

OpenStorm design will handle normal operating conditions and also faulty conditions, consequential faults, and external influences such as temperature, altitude, pollution and moisture.

- The safety design for OpenStrom includes:
- Enclosure design for protection of electrical shock and energy related hazards;
- Enclose will have a high value of dielectric insulation
- Enclosure's material will be high resistive to fire , climate factors and electromagnetic radiations;
- The component selection, circuit design and enclosure will be done to protect the device from currents overload, insulate breakdown and by this way will protect the device from the temperature shock and fire
- Protection against mechanical hazard will be reach in enclosure design where the sharp edges and corners will be rounded

Schematic

The complete schematic is available at:
https://www.dropbox.com/sh/ot0jd58d2qf6njz/AAB8RIcgBR5rNrH3Oqq_DbuMa?dl=0