System for intelligent measuring, registering and control in electrical substation

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The paper presents novel idea for construction of intelligence systems for measurements, data collection and control in MV/LV substations. The technical solution is based on developed microprocessor control systems. The system include software and algorithm for optimizing of connected transformers, reducing power and energy losses and improving of energy efficiency in industrial and urban electrical distribution systems. The control system is applicable for all kinds of connection schemes in MV electrical network and level of voltages 20,10 and 6 kV.

Система за интелигентно измерване, регистриране и контрол в електрическа подстанция (Росен Василев, Владимир Чиков, Валентин Гюров, Ивайло Неделчев, Стоян Ташев, Асен Кръстилев, Цветан Алистаров, Наталия Николова). *Тази статия представя иновативна идея за изграждане на интелигентна система за измерване, събиране на данни и контрол в подстанции на средно напрежение (Ср.Н.). Техническото решение се основава на разработена микропроцесорна система за контрол. Системата се състои от софтуер и алгоритъм за оптимизиране на свързани в система трансформаторни подстанции, намалявайки консумираната мощност и енергийните загуби и подобрявайки енергийната ефективност в индустриални и градски електроразпределителни системи. Системата за контрол е приложима за всички видове схеми на свързване в мрежи средно напрежение с номинални напрежения (20, 10 и 6 kV).*

Introduction

At present it exists a lot of variety of different technical systems, with big functionality, which are approved and made in big worldwide companies (Siemens [6], Schneider Electric [7], ABB [8], General Electric [9])

In spite of re-covering of the terms like „SMART Systems" "Intelligence Systems", „SCADA Systems" and many more, all approved innovations lay on the similar topology, which consist of following units:

- net analyzers and/or solid state electricity meters;
- condition indication elements;
- programmable logic controllers (PLC);
- executive elements;
- software maintenance for PLC;
- software maintenance in SCADA class;
- communication unit (TTL, Ethernet, GPRS);

Systems classified as "control and registration of consumption", "System for energy management", "Telecontrol (telemanagement)" as well as "service management" systems essentially uses the same or simplified hardware base and maintenance. The differences are in software basement of SCADA class.

Possibilities for development of the system of new type.

Opportunities, which are selected for development of new type intelligent system are as follows:

1. Introducing real control via flexible regime variation of the power transformers, aiming maintenance of the optimal load and efficiency.
2. Integrating of the monitoring function of the protective equipment for low voltages and occurred emergency events in complex system for intelligent control.

Determination purpose of the project

Determination purpose of the project depends on following factors:

- Realizing of the technical solution, which will be simple, low price and adapted to traditional electrical substation (ES) which belong to present generation;
- At present electrical distributing companies are situated in telemanagement systems and this solution must be in accordance with approved

systems. This will ensure practical realization of the innovation.

- Technical development must be optimal of technical-economical aspect, i.e. financial and technological resource must be orientated to real energy saving (direct economy effect), improving reliability and ergonomics (exploitation rate), which is indirect economy effect.

Technical solution

In result of studies was defined following requirements to technical solution, which can be viewed as initial restricted conditions:

1. System must have high unification rate i.e. it should be able to join to most of present technical solutions of transformer's ES in MV/LV.
2. System can be able to get application for reconstruction of existing or building of new ES.
3. System must allow full monitoring of the electricity of MV and LV side of the transformer.
4. System can be able to control on MV and LV side of the transformer.
5. System must meet requirements for exploitation of the ES's.

In accordance of these requirements, can be summarized:

- In republic of Bulgaria as well as the most countries members of the EU standard MV's are 20, 10 and 6kV.
- In republic of Bulgaria as well as the most countries members of the EU standard LV's are 400/230V.
- The most populated solutions are one or two-transformers schemes. For industrial power supply systems (PSS) as well as any large hotel complexes are used three and four-transformation ES.
- Regarding the supply side of the transformers (MV), often is used diagram with main closed line i.e. serial connection of the ES's from powered side. Radial diagram is used only in industrial PSS aiming more reliability in power supplying in case of emergency of any ES.
- The base working regimes of the power transformers are – separated and combined. More used is combined regime of work. Parallel work is mainly used for industrial PSS, where qualified staff is permanent available.

With reference to these facts, are defined first group of technical requirements:

Requirements in accordance with the configuration and arrangement of the ES's:

- Developed system must support the measurement and control of one, two, three and four transformer substations;
- Developed system must be able to support measurement and control in ES's configured for serial and radial scheme.

Requirements for measurement:

- Developed system in terms of the measuring part, must support measurements of MV side as follows:
- For level 20, 10 and 6 kV: measured secondary voltage from voltage measuring transformers – 100V and 100 / √3 V, depending on their connection (Y or delta), i.e., the measuring section can be unified for the three voltages 20, 10 and 6kV, the configuration may be done manually by setting a software measurement constant.
- Developed system in terms of the measuring part, must support measurements of low voltage side of 400 and 230V;
- Developed system in terms of the measuring part - current burden, must maintain measurements of MV side when using current measuring transformers 5 and 1A;
- Developed system in terms of the measuring part - current burden, must maintain measurements of LV side when using current measuring transformers 5 and 1A;
- Therefore measuring part of the current signals can be unified as well as for MV and for LV.

Control requirements:

- Developed system must be able to control the MV switch-disconnectors and/or switches with two independent signals – turn on and turn off;
- Developed system must be able to control the LV switches with two independent signals – turn on and turn off;
- Developed system must be able for monitoring of the switching protective equipment stages as follows:
- Turned on;
- Turned off (by control);
- Turned off (by protection).

Additional safety work requirements:

- Prevention electric connection between MV an LV measurement circuits.
- Optocoupler isolation between microprocessor and entire measuring circuit.

In accordance with latest technical requirements the next engineering solution regarding topology of the system is assumed:

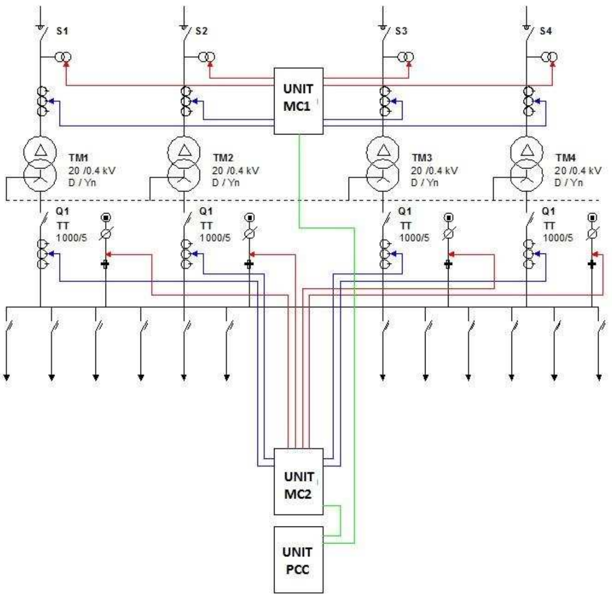

Fig.1. Measuring topology. Current circuits –blue lines, Voltage circuits – red lines. RS communication – green lines.

- Usage of the four unit configuration in the next structure (figure 1):
- Unit MC 1 (Measurement & Control 1). This unit process four MV side measurement signals (by voltage and current), watch MV switching protective equipment condition. It has its own microprocessor part of initial signal processing of the measured values. MC1 has serial communication (RS), whereby two-way data exchange with the main unit - PCC (Primary Control and Communication) is realized.

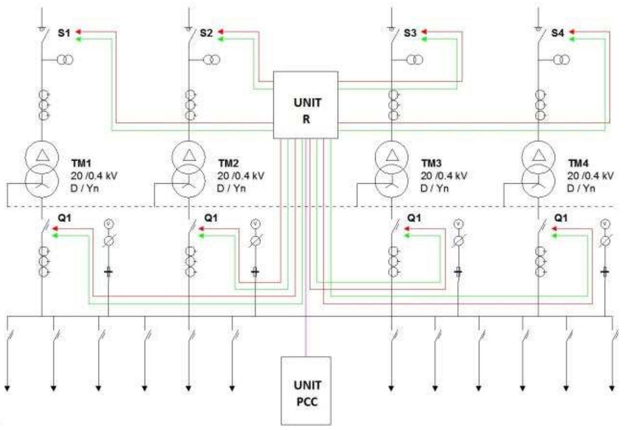

Fig.2. Control topology. Turn on signals – red lines, Turn off signals – green lines. RS communication - magenta.

- Unit MC2 (Measurement & Control 2). This unit has the same functions as MC1, but it concerns to the LV side.
- Unit PCC. In this unit centralized control by build in algorithms is executed, using received data from serial communication port. It has its own processor, maintain autonomous serial communication channels to other units. Cover user interface via touch screen display, which can help to local visualization of the electricity consumption regimes, diagram configuration as well as fixed user settings.
- Unit R. Executive unit which depends on PSS. It executes power commutation of the switching protective equipment of the MV and LV side via 16 relays with main circuit on 230V AC and 5A. It has its own processor unit and communication module for connection to the PCC unit.

Each of the units has been designed with its own power supply unit and all these devices are built to meet DIN requirements for installation.

System's components

In accordance with the adopted system architecture for measurement and control is performed choice of several different microprocessor systems for each unit.

Main unit PCC

It was chosen development system Arduino Due, which consist of Atmel SMART SAM 3X/A controller, based on APM Cortex M3 RISC processor. To the main module was developed additional hardware configuration including LCD touch screen display, power supply unit and supplementary peripheral card.

Technical characteristics of Arduino Due

Arduino Due is the first controller which belong to Arduino set, operating with 32-bit ARM microcontroller. It posses 54 digital inputs/outputs (12 of them can be used for PWM outputs), 12 analog inputs, 4 UART (hardware serial ports), working frequency 84 MHz, USB OTG connection, 2DAC (digital-analog convertors), 2 TWI, hardware "reset" and "erase" buttons.

Core description:

- 32-bit, 4 bytes wide data with single CPU Clock;
- CPU Clock – 84MHz;
- Mempry 96 Kbytes SRAM;
- 512 Kbytes Flash Memory;

For implementation the interface with local touch-screen display, to standard configuration of Arduino

Due (figure 2) is attached supplementary module and one additional module with four serial ports for communication with other system's components.

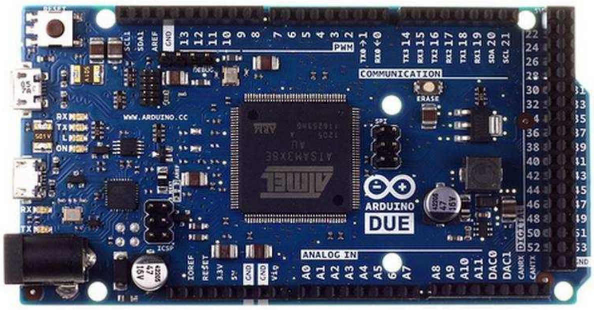

Fig.3. Standard Arduino Due controller. Common view.

Selection of the processors for MC1 and MC2 units.

For decentralization of the measurement functions, registration and control is assumed using both separated processors for these measurement units (MC1 and MC2). For units MC1 and MC2 are chosen 8-bit processors AT Mega 128 (with 128kBytes build in flash memory) from Atmel.

Selection of the suitable diagram solution for measurement unit.

Current signals from MV side are measured with current measurement transformers. According to established standards for measurements devices, current signal must be in interval 0-5A (standard nominal values are 1A and 5A) depending on the load. Four measurement fields for MV require 12 current signals, which are registered and processed in unit MC1. The situation is the same for the current signals from LV side (12 channels in interval 0-5A).

Voltage signals from MV side are measured with the help of current and voltage measurement transformers. In accordance with standard secondary voltages for MV measurement transformers, input voltage for MC1 unit is 100V and for 230V for MC2 unit.

For signal processing in unit MC1 is chosen specialized IC - ADE 7758 from Analog Devices.

Short description of ADE 7758:

- High precision – measurement error less than 0,1% for active energy by 25°C ambient temperature.
- Meet standards IEC68687, IEC61036, IEC61268, IEC62053-21, IEC62053-22 and IEC62053-23;
- Application in three-wire three-phase, four-wire three-phase networks and three one-phase networks.
- Capable to measure apparent, active and reactive energy, RMS value of the currents and instantaneous value of the digitized currents and voltages.

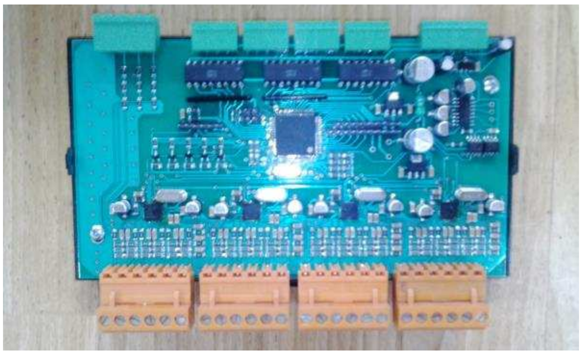

Fig.4. MC1 unit for measurement and control. Common view.

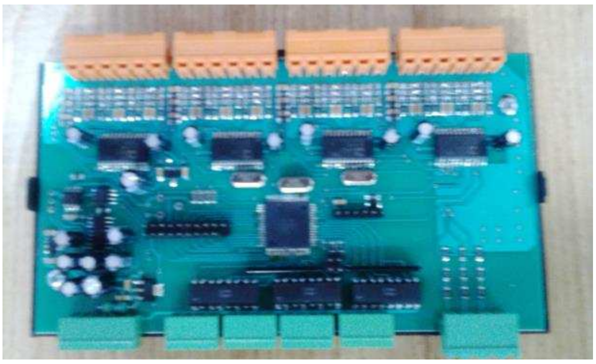

Fig.5. MC2 unit for measurement and control. Common view.

Fig.6. Power supply unit. Common view.

Algorithm of operation

Principle of operation of this system is shown on fig.7. After starting the program the constants, number of working transformers, rated current, rated voltage and others are reset. Here are considering display parameters manually set by the user's terminal with Touch Screen.

Subsequently is performed three procedures (1,2 and 3) to make a connection with the controllers for medium voltage (MC1), low voltage (MC2) and actuators (R).

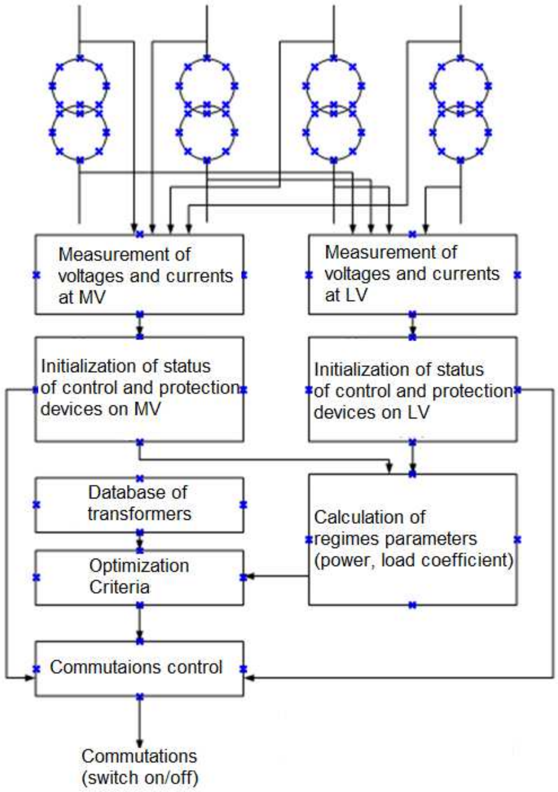

Fig.7. Block diagram of the algorithm of operation.

In case of unsuccessful initialization signal is generated error and closes internal cycle of the program until a successful initialization is performed. Upon successful initialization is passed to the reading of the data from the two controllers. The next procedure is to determine the optimum number of the working transformers depending on the mode of the load.

The necessity for conducting switching operations is determined by the internal programming algorithm according to the criteria of optimality and status of switching protective devices (whether off or disconnected from the protection switching element). If there are turned off element from protection switching is prohibited.

If switching commutations is needed commands for performing physical commutations are downloaded to the switching controller (R), and hence there are being implemented subsequently. If there is no necessity of performing commutations it is closes internal cycle to crosscheck on the newcomers data from MC1 and MC2 modules. This cycle is built with internal delay (Delay).

If is needed to perform switching, again closes internal cycle with a corresponding delay, which is waiting for data for a new data from MC1 and MC2 modules after the implementation of the commutation. In order to avoid unwanted commutations internally algorithm is set to optimized dead band management.

The optimization criterion is ΔP = f (β). In general, for n number of power transformers, limitation power S_{rn}, after which the work of the (n-1) CT will continue to operate in parallel to n working CT is determined by the expression:

$$S_{rn} = \left(S_{н1} + S_{н2} + \ldots + S_{нn}\right) \cdot \sqrt{\frac{\Delta P_{0n}}{\left(\frac{S_{н1} + S_{н2} + \ldots + S_{нn}}{S_{н1} + S_{н2} + \ldots + S_{н(n-1)}}\right)^2 \left(\Delta P_{k1} + \Delta P_{k2} + \ldots + \Delta P_{k(n-1)}\right) - \left(\Delta P_{k1} + \Delta P_{k2} + \ldots + \Delta P_{k(n-1)}\right)}}$$

where S_{Hn} is rated power of the n-th transformer;

ΔP_{Kn} are short connection losses for the n-th transformer;

ΔP_{On} are open circuit losses for the n-th transformer..

If transformer are unique, the expression can be transformed into:

$$S_{rn} = nS_н \sqrt{\frac{\Delta P_0}{\left(\frac{nS_н}{(n-1)S_н}\right)(n-1)\Delta P_k - n\Delta P_k}} =$$

$$= S_н \sqrt{n(n-1)\frac{\Delta P_0}{\Delta P_k}} = S_н \sqrt{n(n-1)K}$$

or:

$$\beta_n = \frac{S_{rn}}{S_н} = \sqrt{n(n-1)K}$$

Technical characteristics of the system

- Observed points – 8 three phase points which consist of 4 on LV and 4 on MV.
- Control of the outdoor switchgear Q1, Q2 of MV side via turn on and turn off signals (for motor controlled automatic MV circuit breakers) or contactor’s control (in case of fuse protection).

- Circuit breaker and power circuit breaker control via turn on and turn off independent signals.
- Build in logic for operational switches sequence.
- Criterion control $\Delta P=f(\beta)$ – minimum and/or $\Delta P=f(P, PF)$ – maximum.
- Feasibility

The construction of this type of system provides a **direct savings** of electricity, due to the observing of minimum losses depending on the power of the number of users by providing optimal transformers load. Direct economic effect - up to 2-5% of the total load mode and up to 60% reduced power consumption in standby (in the night hours or seasonal consumers - resorts, etc.). Indirect savings from energy management. It shows using of centralized system, carrying

Conclusion

This report represented development of a new type technical configuration for intelligent measurement, registering and control in ES. It operates as centralized system, implementing monitoring and control instantly as well as on MV side and LV side of the ES's. Author's software for control based on optimum criterion $\Delta P=f(\beta)$ – minimum and/or $\Delta P=f(P, PF)$ – minimum. Direct economy savings from main consumption, as there are also indirect effects of improving the operation and opportunities for energy management.

Acknowledgements

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