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Features of the Implementation of an Over/Under Voltage Relay on STM 32 Microcontrollers

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***Abstract*—The purpose of the research is to analyze the effectiveness of the STM32 microcontrollers usage of in the implementation of the load relay protection from mains voltage surges based on the analysis of the root mean square value of the mains voltage and the detection of impulse noise. The research included: development of a projects group for various compilers, microcontrollers and software writing algorithms, as well as performance measurements of all program blocks. As a result of the research, requirements were presented for the value of the microcontroller clock frequency, which is sufficient to detect impulse noise with a duration from 10 µs. An algorithm is also proposed to reduce the requirements for the value of the clock frequency and the amount of RAM.**

Keywords*—*relay, microcontroller, algorithm, root mean square voltage, performance.

I. Introduction

For trouble-free operation of electronic devices, strict compliance with the requirements for the operating voltage range and the absence of impulse noise is necessary. Protection is provided by circuit solutions of electronic devices and special protection devices (relays), which turn off the power to electronics when the operating voltage exceeds the upper limit or the voltage drops below the lower limit, as well as when impulse noise is detected [1, 2]. An example of an emergency load shutdown relay is MP-63 DigiTOP. Overvoltage, undervoltage and time delay limits are configurable. The lower limit can be set within 120-200 V. The upper limit is within 210-270 V. The maximum response time to a voltage drop below the lower limit is up to 1s, and above the upper limit is up to 0.06s. It also provides protection by the value of the current in the load. The values of voltage limits, time delays and reaction times in such relays are set by the standards IEC60898-2, IEC 61850, etc [3].

These devices are implemented on hard logic or using microcontrollers [4-7]. If microcontrollers are rarely used in cheap household devices, then they are always used in industrial protection relays. The SIEMENS 3UG4617-1CR20 industrial relay has a built-in Profibus interface for logging network parameters and emergency situations on the server of the automated control system. The usage of microcontrollers makes it easy to reconfigure the protective relay parameters: voltage values, time delays, measurement results averaging time. Protective relays use microcontrollers from various manufacturers TI, Atmel, etc. In recent years, STM32 microcontrollers from ST Microelectronics have been widely used in industry [7, 8]. The STM32 family of microcontrollers contains several popular series that differ significantly in performance, features and price. The purpose of the research was to evaluate the usage effectiveness of the various series of STM32 microcontrollers for the implementation of protective relays as well as the development of optimal algorithms for measuring and processing the results of these measurements in modern environments for compiling program code [9, 10].

II. Calculation a Root Mean Square Voltage

A. *Methods for calculating the root mean square voltage value*

Variable mains voltage is characterized by such parameters as [11-13]: peak value V_p and root mean square value V_{RMS} (fig.1). The main parameter that the protective relays control is the root mean square voltage.

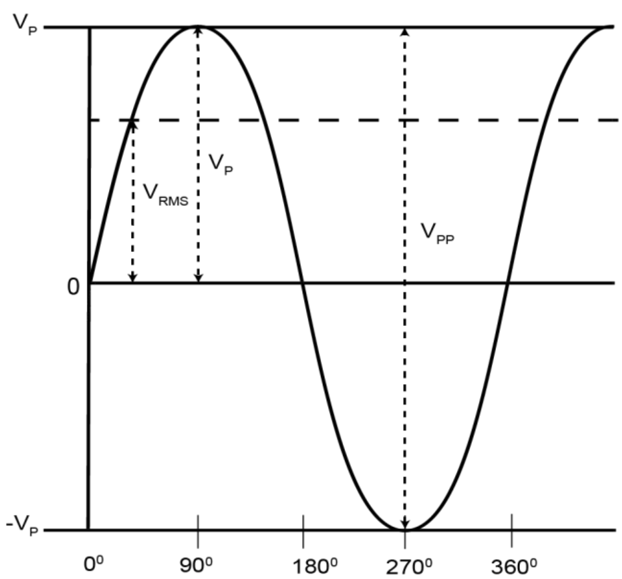

Fig. 1. Frequency response of the synthesized low-pass filter.

A simple formula can be used to calculate V_{RMS}

$$V_{RMS} = \frac{V_p}{\sqrt{2}} = \frac{V_{pp}}{2\sqrt{2}}. \quad (1)$$

When calculating V_{RMS}, it is enough to measure the peak value of the positive half-wave voltage. However, in order to eliminate errors when the negative half-wave disappears, the difference between the peak values of the positive and negative half-waves is used. But this method also gives a significant error when the shape of the sinusoidal voltage is distorted [7, 11]. Such distortions occur when using generators or during the on-off processes of a powerful load. In this case, the formula is applied

$$V_{RMS} = \frac{1}{T}\int U^2(t)dt, \quad (2)$$

where T – is the time multiple of the mains voltage period. When using an analog-to-digital converter to measure the input voltage at a sampling interval, a discrete formula for calculating V_{RMS} is obtained.

$$V_{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} U_i^2}, \quad (3)$$

where N is the number of measurements for 1 period of mains voltage. Since the mains frequency has a certain instability and may differ from the fixed value of 50/60 Hz, the mains voltage zero selection schemes are used. Having information about the moments when the mains voltage passes through 0, it is possible to accurately determine the number of samples N, which corresponds to 1.2 ... periods of the mains voltage.

Modern protection relays disconnect the load based on the analysis of the effective voltage for 1-10 periods of mains voltage [7, 13]. Some of them can analyze impulse noise and turn off the load when the impulse amplitude exceeds a predetermined value. In such relays, the analysis time is usually 0.1 ms. Based on studies [4] pulse duration can be from 10 µs. From the analysis of the characteristics of existing protection relays and scientific research, it follows that the sampling rate of the analog signal should be from 10 kHz to 100 kHz, which corresponds to the analysis times of 0.1 ms and 10 µs.

With a mains voltage frequency of 50 Hz and a sampling rate of 10 kHz to 100 kHz, one period of the mains voltage will correspond to from 200 to 2000 input voltage samples. The STM32 microcontrollers use a 12-bit analog-to-digital converter and 2 bytes are needed to store one reading, and up to 4 kB to store the conversion results. Even microcontrollers of the cheapest STM32F0 series satisfy this requirement for the amount of RAM. To calculate V_{RMS} according to (3) in one period (20 ms), it is necessary to perform N multiplications and additions, one division and calculation of the square root. It is also necessary to perform N multiplications to convert the code at the output of the ADC to a voltage value. All operations must be performed with floating point numbers. In the STM32 line of microcontrollers, only starting with the rather expensive F4 series, floating-point calculations are implemented at the hardware level.

B. *Measurement and calculation algorithm*

In STM32 microcontrollers, when converting an analog signal into digital form, the mode of periodic ADC measurements was selected. In this mode, the ADC conversions are started by a timer. Also, interrupts from this timer were used to compare the last measurement result with a threshold value corresponding to the amplitude of the detected impulse noise. When this threshold was exceeded, the load was turned off. To speed up the transfer of measurement results from the ADC to the RAM, a direct memory access controller was used. An interrupt from the DMA controller at the end of the array filling was used to start the V_{RMS} calculation. Since the calculation of V_{RMS} takes a significant amount of time, when the array is cyclically filled with ADC measurement results, the old values are overwritten with new ones. This led to calculation errors. To solve the problem, 2 options were analyzed. In the first case, the elements of the array of measurements were copied to the array by which V_{RMS} is calculated. In the second case, 2 arrays were used. After filling the first array, the operation of the ADC was suspended and the ADC was started with the transfer of the measurement results to the second array. Then the first array was used again. That is, writing to the arrays was performed in turn.

III. Research Results

For research, 2 identical hardware configurations were created based on cheap STM32F030 and STM32F102 microcontrollers with clock frequencies of 24 and 48 MHz. To compile the developed programs, two popular platforms IAR Embedded Workbench 9.1 and STM32CubeIDE 1.6 were used today. The V_{RMS} calculation was performed in the body of the main calculation loop with the lowest priority. The calculation time for V_{RMS} based on 200 measurements for a period of mains voltage in IAR Embedded Workbench was 8092 cycles without optimization and 7504 cycles with a low level of performance optimization. In STM32CubeIDE these times are 8230 and 7612 respectively. Thus, the calculation time does not exceed 0.4 ms at a clock frequency of 24 MHz and 0.2 ms at a clock frequency of 48 MHz. To detect impulse noise with a duration of 10 µs or more, the sampling period is 10 µs, which corresponds to 240 cycles at a clock frequency of 24 MHz and 480 cycles at a frequency of 48 MHz. During this time, the microcontroller must process the interrupt from the ADC and turn off the load if necessary. According to the results of the study, it takes up to 21 cycles to enter the interrupt handler subroutine. In an interrupt, it is imperative to reset the interrupt flag, since it does not automatically reset itself. This operation requires 22 cycles. Another 32 cycles are needed to compare the last ADC measurement result with the threshold and turn off the load if necessary. Thus, from 15% to 31% of the sampling interval is used for the detection of impulse noise and load control, depending on the clock frequency of the microcontroller. At the end of the filling of the array of measurements of the mains voltage for the period of this voltage, an interrupt from the DMA controller occurs. If in the handler of this interrupt to copy 200 array elements, then 374 cycles are required. If you restart the ADC and change the array in which the measurement results are stored, then 270 cycles are required.

Conclusions

STM32 microcontrollers with a clock frequency of 48 MHz or more make it possible to implement a surge protection relay. At this clock frequency, the microcontroller has time to analyze impulse noise with a duration of 10 μs, copy 200 measurement results or restart the ADC when working alternately with two buffers. When using microcontrollers with a clock frequency of 24 MHz, the method of working with two buffers is inefficient, since it takes a fixed number of cycles to restart the ADC. The method of copying an array of values is more efficient, since the size of the buffer can be reduced to 100 dimensions. This will cut the copying time in half. Disconnecting the load when the V_{RMS} threshold is exceeded is a lesser priority. The V_{RMS} calculation time is no more than 2.5% of the mains voltage period and fully complies with the requirements for this parameter for such devices. The best performance when compiling a program is provided by the IAR Embedded Workbench compiler. Thus, even on the simplest STM32F0 microcontrollers, it is possible to implement a load protection relay, which ensures the economic competitiveness of such devices.

References

[1] Venkateshmurthy B. S., Nataraj K. R, Rekha K. R3, Mallikarjunaswamy. S “Implementation of Under and Overvoltage Protection Relay in Power System” *International Journal of Innovative Research in Science, Engineering and Technology* Vol. 6, Issue 7, 2017.

[2] Viktor Milardic, Ivo Uglesic, Ivica Pavic, Member, IEEE, “Selection of Surge Protective Devices for Low-Voltage Systems Connected to Overhead Line” *IEEE Transactions on Power Delivery*, 2010, pp. 1530-1537.

[3] IEC 60898-2-2011 Circuit breakers for protection against overcurrent electrical installations for domestic and similar purposes. Part 2. Circuit breakers for AC and DC http://vsegost.com/Catalog/52/52503.shtml

[4] Adeel Saleem, Atif Iqbal, Kashif Mehmood, Adnan Samad “Modelling and Implementation of Microprocessor Based Numerical Relay for Protection Against Over/Under Current, Over/Under Voltage” *Journal of Computational and Theoretical Nanoscience* Vol. 17, 2020, pp.1-7.

[5] Rajveer Singh, Rajendra Kumar, Rebecca, Hamzah Shabbir, Abdullah Zahid “Over/Under Voltage Tripping Circuit for Distributed System Load with GSM alert using Microcontrolle” *International Journal of Innovative Technology and Exploring Engineering*, Vol. 8 Issue 9, 2019, pp.1335-1339.

[6] Ali Peiravi “Design and Prototyping of a Microcontroller Based Synchrocheck Relay for Improved Reliability” *Journal of American Science* Vol. 5, 2009; pp.181-188.

[7] Ömer Özgür GENCER, Semra ÖZTÜRK, Korhan KARAARSLAN “Performance of an Over/Under Voltage Relay at Non-sinusoidal Conditions” *IEEE MELECON 2006*, 2006, pp.1102-1105.

[8] Nugraha, Ravi, Priyambodo, Realdo, Ivanuri, Safitri, Zakariz & Messiah “Use Of ACS 712ELC-5A Current Sensor on Overloaded Load Installation Safety System” *Applied Technology and Computing Science Journal*, Vol. 1, No. 47, 2021, pp. 47-55.

[9] O. Zubkov, I. Svyd and O. Vorgul, "Features of the Digital Filters Implementation on STM32 Microcontrollers", *2021 III International Scientific and Practical Conference Theoretical and Applied Aspects of Device Development on Microcontrollers and FPGAs*, 2021. doi: 10.35598/mcfpga.2021.001.

[10] O. Zubkov, I. Svyd and O. Maltsev, "Features of the use of PID controllers when controlling evaporators", *2020 II International Scientific and Practical Conference Theoretical and Applied Aspects of Device Development on Microcontrollers and FPGAs*, 2020. doi: 10.35598/mcfpga.2020.001.

[11] O V Arkhipova, N N Dolgikh, V Z Kovalev, D S Osipov, A O Paramzin and V A Tkachenko “Developing the calculation methods of effective values of current and voltage for nonsinusoidal transient modes in electric power systems based wavelet transform” *IOP Conf. Series: Materials Science and Engineering 2021*, pp. 1118-1124.

[12] John Clayton Rawlins M.S. Basic AC Circuits (Sec. edition) 2007.

[13] Ham Do-Hyun, Kim Soo-Bin, Song Seung-Ho, Lee Hyun-Young Accurate “Calculation of RMS Value of Grid Voltage with Synchronization of Phase Angle of Sampled Data” *The Transactions of the Korean Institute of Power Electronics*, Vol. 23 Issue 6, 2018, pp.381-388.