Realization of the Universal Microcontroller Power Regulator

Vladan Vučković [1]

Abstract - **The paper presents basic construction principles of the universal electronic power regulator using the microcontroller Microchip PIC16F84 coupled with optoelectronic component and standard triac BT 139/800. The device runs using the phase control of the network alternating power current and could be used for a control of many non-inductive apparatus like light bulbs or halogen lamps as well as for some kind of electric collector motors. As the one of the most important purposes, some application details in light control technique are also presented.**

Keywords - **AC voltage controllers, Microcontrollers, Power regulation using phase control, Signal processing**

I. Introduction

The paper presents basic realization principles of the universal power regulator [1],[2] using the microcontroller Microchip PIC16F84 [3],[4] coupled with optoelectronic components and standard triac BT 139/800 [5]. The presented device runs using the *phase control* of the network alternating power current and could be used for a control of many non-inductive apparatus. The power consumption of some tested devices was up to 3kW. The possibility of the precise power control of the connected consumers without their modifications maintains different possibilities in home and industrial applications. The construction does not provide usage of the electromagnetic relays or other mechanical and moving-parts components so it is very reliable in intensive practical exploitation. The embedded microcontroller enables the construction of the very complex control programs that could not be reached by some other digital circuits (counters, timers) [6]. The power regulator is universal, so the same hardware could be used in different application; the changes are only in software. The basic principle of the electronic power regulator is well known and has applied in different devices: light control systems, halogen lamp power controlling, and electric heater control... In industrial literature for this class of the power regulators some synonyms are used like *AC voltage controllers or dimmers* [2].The functionality of the regulators is based on output thiristor and triac electronic component characteristics. Particularly, these semiconductor components have possibility to conduct currents up to 40A with low lossiness controlled by the proportionally extremely low gate current. When triac is in conductive state it could be disabled only when voltage between anode and cathode is zero. Thus, if the triac runs in alternating 220V current circuit each sinusoid passing through the zero turn off triac so its consequential activation could be controlled in wide range, into the positive or negative half-period. The described functionality is the base for the device realization. With development of the modern microcontroller technology the electronic device designers are in position to use small, compact and cheap microcontrollers in low scale embedded devices. The advantages for using the microcontrollers, as the main controlling unit in electronic device is huge compared to the application of some other solutions based on digital and analogue circuits. First of all, the dramatic hardware simplifications are achieved because the solution of the concrete functional problems is transferred to the software - the microcontroller machine program. Thus, maximal functionality and low manufacturing costs of the device are achieved at the same time. These arguments have determinate the construction of the presented device itself.

II. The Theoretical Principle of the AC Voltage Phase Control

Let us analyze network current diagram presented in Fig. 1. For the reasons of simplicity let us suppose that the device, which is coupled, has non-inductive character, so there is no phase difference between current and voltage diagrams. It is well known that capacitate and inductive resistors in electric circuit generate phase difference between current and voltage, but it is not crucial for the following analyze.

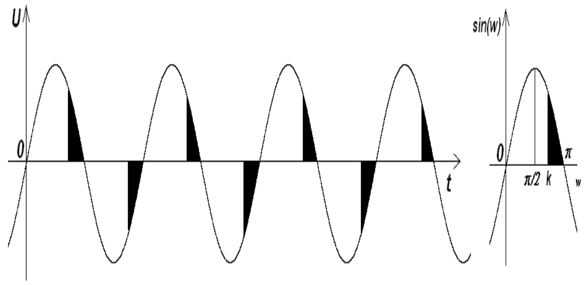

Figure 1. (a) Network sinusoid with active arrays
(b) Half-period of sinusoid

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So, the basic assumptions are still that the current and voltage diagrams are folded. The other presumptions are that activation of the device is synchronized by the constant delays after the zero values of a current sinusoid.

Dark arrays in Fig. 1 (a) show active districts when device gets energy from the network. It is obvious that total power consumption in that situation is less then full (nominal) power consumption. Also, it is well known that the power that conveys to consumer is proportional to the active – dark array on current/voltage diagram.

Thus, principle of power control could be formulated in following way: *The power regulation is based on control of the turn-on delays after the zero-cross in every period of the sinusoidal network alternating current.* The solution of power control is transited to the time delay problem control that is much easier to solve. The fact is that nominal power of the consumer is not significant for the basic functionality although it determines the power and maximal current of the output triac.

To determine quantitative parameters that represent power control we will use simply model presented in Fig. 1 (b). The half-period in Fig.1 (b) is analogue to the half-period of network sinusoid current. The time delay is marked with variable k. The portion of energy, which conveys to the consumer, could be determinate by including the F_P factor that represents the proportion between dark array and total array under the sinusoid. The F_p factor could be calculated by the proportion of the sinus function integral in interval $[k,\pi]$ (dark array) and $[0,\pi]$ (full half-period):

$$Fp = \frac{\int_k^\pi \sin(w)dw}{\int_0^\pi \sin(w)dw} = \frac{\cos(\pi)-\cos(k)}{\cos(\pi)-\cos(0)} = \frac{\cos(k)+1}{2} \qquad (1)$$

After the integration, we get equation $\cos(k)=2F_p-1$ and $k=\arccos(2F_p-1)$. This formula enables to determine the time delay if one knows the F_P factor. To calculate real conditions let us postulate proportion $\frac{\Delta\tau}{k} = \frac{10ms}{\pi}$ where $\Delta\tau$ is delay presented in miliseconds. Nominal network frequency is 50Hz so one periode lasts 20ms and a half of periode lasts 10ms, as it was shown in last proportion. After the combination of two formulas we could postulate practical formula to determine time delay in miliseconds if we know the target F_P factor:

$$\Delta\tau = \frac{10\arccos(2Fp-1)}{\pi} \text{ (ms)} \qquad (2)$$

By changing of the input values in formula (2) we could precisely generate the time delay in one half-period to achieve the target F_P factor. If we change F_p from 0 to 1 with constant step value (for instance 0.1 or 10%) and successively apply formula (2) the following table values are generated:

TABLE 1. TIME DELAYS ACCORDING TO TARGET F_P FACTOR.

Fp (%)	**Δt (ms)**
0	10.000
10	7.952
20	7.048
30	6.310
40	5.641
50	5.000
60	4.359
70	3.690
80	2.952
90	2.048
100	0.000

It is clear that the non-linear function for time delay requests that formula (2) must be applied for each value if we want to determine the output value precisely. But in real time applications it is not suitable to use the formula (2) in its original form and the approach is rather numeric. Every equidistant value from the Table 1. is memorized in microcontroller hash memory in hash table with the liner approximation between neighbor values. This approach has excellent trade-off factor between access time and functionality. We could increase the precision by decreasing the numeric step between values but that increases the numbers of elements in hash table. From Table 1., it is obvious that the difference between neighbor values is most exposited near the begin and end where the origin sinusoid is aslope (Fig 2).

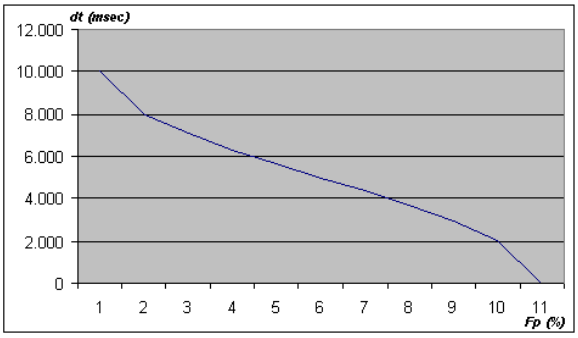

Figure 2. Δt in function of the F_p.

III. TECHNICAL DETAILS OF THE CONSTRUCTION

Based on theoretical results presented in previous Section we could proceed to the technical solution that will realize hardware device construction (Fig. 3). The description of the functionality for some sub-segments also with component characteristics is presented:

- **Output Subsystem** – Power component triac BT 139-600 is used. Triac could lead alternating currents up to 16A. Maximal consumer power that could be controlled by the device is about 3.5 kW (for the nominal voltage 220V). When high current values are present the triac must be equipped with metal cooler.

- **Microcontroller** – The whole device is organized around the microcontroller PIC16F84 that is also the central functional part providing the control algorithm. The procedure could be described in following steps:

    1) Determine the start point of the half-period for alternating network current and reset the timer. Triac is inactive in this moment due to the input voltage zero values.
    2) Determinate the delay constant in milliseconds using the value of the target F_P factor. Nevertheless use hash table analogue to Table 1. for fast approximation of the function (2).
    3) Turn-on output switch unit (triac).
    4) Wait for triac activation time; a few hundred of microseconds adjective to component type.
    5) Turn-off (gate) triac. In that point the input voltage is still different from zero, so triac will continue to conduct.
    6) Goto 1)

The central component Microchip PIC16F84 is choosen for device realization. This microcontroller is perfectly suitable due to its functionality and adaptability. The processor is clocked with 4 Mhz crystale oscillator that enables stable and aquarate time cycles.

- **Electronic Coupled Unit** – is realized using the optotriac component MOC 3020. It's breach voltage is about 7.5 kV. The optoelectronic component is controlled by the processor from the input side and it generates gate excite current for triac as the output. This unit enables galvanic volage decouplation from the 220V network that menages high safety for the low voltage electronic components.
- **The Electronic Circuit for Zero-Cross Detection** – it uses alternating signal from the secondary of the transformer 220V/6V that energizes the microcontroller. Compared with network current, the signal is in opposite phase having the same frequency so it could be used for realization of the 1) step in main algorithm.
- **Rectifier** – standard Graetz bridge rectifier, that also uses electrolytic condenser 470μF and stabilisator 7805 enabling +5V DC for microcontroller.

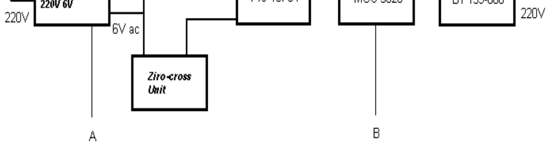

Figure 3. The block scheme of the universal electronic power regulator.

IV. Realization of the Device

The block scheme of the device is presented in Fig. 3. The construction of the device is compact so it can be embedded on 3x5 cm wafer. It possesses many useful technical characteristics and it is very confident in heavy exploitation conditions. First of all, microcontroller part of the device is galvanic decoupled from one side with transformer (A) and from the other side with opto-triac (B). Also it is grounded separately enabling very high level of resistance to networks peaks and disturbance. The adaptive algorithm reported in Section 3. enables it to follow network frequency changes. It is well known that in winter months due to the high load of generators and extensive consumptions the network frequencies has tendency to decrease. Embedded microcontroller solves the problem very simple because it consistently, period by period, recalculates real delay using the time passed between two successive zero-crossing points, so all corrections could be done in real time. For programming of the microcontroller's machine language the development environment was used [7],[8].

V. The Realization of the Microcontroller's Light Regulator

As we propounded in Introduction, as the practical part of this paper microcontroller light controller was realized. The light controller has original construction that surpasses the similar devices in its class. It possesses all characteristics that are well known for this type of device and also a set of new advanced functions.

The some of the key characteristics of the device is specified:

- Microcontroller's and integrated technology is used for construction of the device. These facts attain high functionality and reliability with low power consumption and costs. The basic circuit is PIC 16F84 microcontroller that is in massive production. The construction does not provide components with mechanical moving parts like relays whereby the malfunction probability decreases.
- Integrated technology enables to develop device onto compact 5x4cm one-side wafer that could be energized with normal line transformers.
- For control tasters, light automat generates alternating signal that could excite kathertons enabling much easier orientation for the users in darkness. From the other hand, alternating current is not restored from network but using the special electronics that moves the current in save reactive domain.
- In the experimental stage automat was very stable and reliable in a view of intensive testing cycles under the heavy working conditions (Section VI).
- Maximal output power is over 2000W (16A). With nominal cooler the device was tested up the power of 1800W (equal to 30 parallel connected 60 W light bulbs). The main circuit must contain only thermo gene resistors: light bulbs or halogen lamps.

- Immediately after turn-on, the temperature of the metal in light devices is low, resistance is low, and so the impulse current occurs. The impulse current is up to ten times greater than nominal working current. This impulse has very negative influence to relays and light bulbs and those devices are blown mostly in this period. Using the special program with electronic output hardware microprocessor generates special wave shape that heat metal conductor in light device to the red incandesce. All process is finished within 0.75 seconds. After that, microprocessor turns on full power. When red incandesce occurs the resistance is 70-80% of the maximal resistance so after the turn-on, the current jump is only 20-30%. All these facts prolog expected lifetime of the light bulls to the factors 5-10 times longer.
- Extracting the activation time – this characteristics enables to extend active time by pressing the taster in the active phase. The automat signals the new status and continues with standard procedure.

VI. TESTING

After a construction of the industrial prototype that possesses all characteristics and components of the final version of device we have performed comprehensive research of the device (Fig. 4) to check all defined functions in real and extreme working conditions [9],[10].

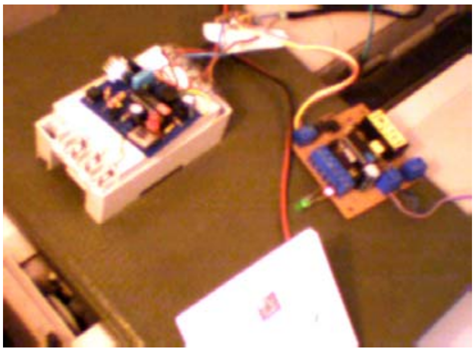

Figure 4. Microcontroller light automat in the testing phase

- **Continually testing** – The device has working in long periods of time continually. After a few months of permanent testing device detained all nominal and projected parameters, so this test was successfully passed.
- **Test of output power** – The large thermo gene loading was connected on output – heaters up to 1000-2000W emulating the large number of lighting bulbs in parallel connection. The device managed this loading without problems but these tests indicated that metal triac cooler is needed. As the maximal nominal output power for the embedded type of triac is 16A, output fuse must be scaled maximally up to 12A.
- **Shock test** – Using the other microcontroller device that controls the power regulator the serious of voltage shocks were emulated. The device was probed in a broad range of possible intervals and frequency of interferences. The tests proved that device construction is very resistant to obstruction by the network glitches also with stable performances.

VII. CONCLUSION

The paper presents theoretical and practical realization of the universal power regulator. The device comprises hardware and software part and it is designed using the Microchip PIC 16F84 development system. The processor doesn't require supporting memory and peripheral integrated circuits that enables realization of the device with extra low number of components. Using the power regulator as the light automat also with connecting with non-inductive light sources like light bulbs and halogen lamps it is possible to regulate the light intensity. In the case of heat consumers it is possible to regulate the temperature by controlling the heater current loading. When some kind of electric collector motors are connected the rotor speed could be regulated [11]. Also many other useful appliance of the universal power regulator is possible. Author's intention is to develop further applications and modifications starting from the basic concept described in this paper.

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