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FOCUS ON

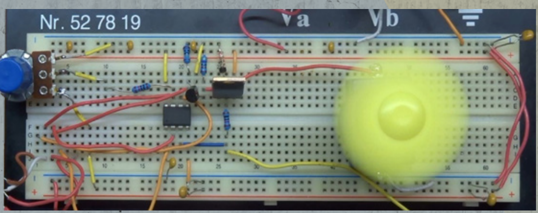
Power & Energy

Mains Power Outages Monitor

Is Your Grid Supply Steadily Available?

Speed Control of a Brushed DC Motor

EMF Measurement Instead of Tachogenerator



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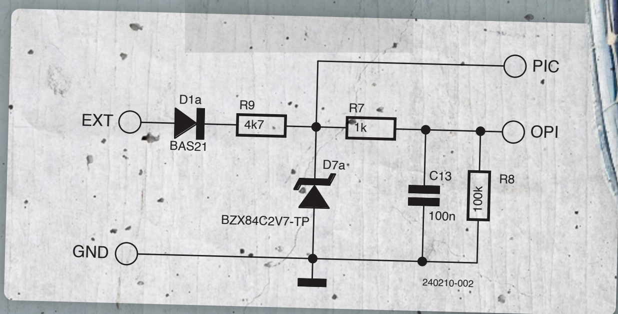
Power Saving Made Easy



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CONTENTS

The **January/ February 2025** edition of ElektorMag is available at newsstands and in the Elektor Store.

EDITORIAL

C. J. Abate
Content Director, Elektor

Bonus Edition Power & Energy Solutions

Looking for more power- and energy-related content? This bonus edition of ElektorMag features additional content to inspire you to design your own solutions. As usual, we include articles on other interesting topics as well.

Is your grid supply steadily available? The article, "Mains Power Outages Monitor," details a circuit that constantly monitors mains power and signals outages.

Before high-power semiconductor-based rectifiers, converting AC to DC in industrial and transportation applications was a significant challenge. Devices were bulky, fragile, used polluting materials, and demanded frequent maintenance. Check out the article, "Mercury Rectifiers," to learn about mercury arc rectifiers and more.

Brush-type DC motors are often replaced by brushless (BLDC) and stepper motors, but their simpler control still has advantages. The article, "Speed Control of a Brushed DC Motor," explores maintaining constant speed regardless of torque — without a tachometer generator.

We hope you enjoy these articles and rest of the content in the Bonus edition. As you work on your own projects, be sure to document your progress on the Elektor Labs platform (*www.elektormagazine.com/labs*)!

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Speed Control of a Brushed DC Motor

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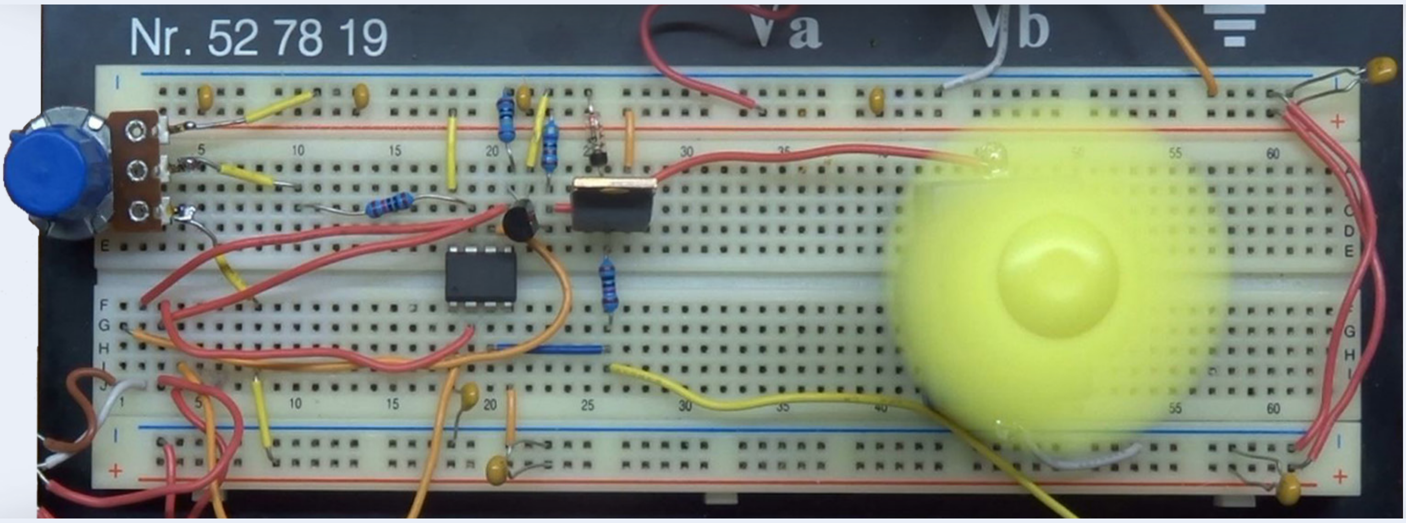


By Rainer Schuster (Germany)

Brush-type DC motors are increasingly being replaced by their brushless (BLDC) and stepper motor competitors. However, their use still makes some sense, as the control effort is considerably lower. This article shows how to keep the speed of a DC motor with brushes constant regardless of the torque – and without a tachometer generator.

In the simplest case, a DC motor is connected to a variable voltage supply, as shown in **Figure 1**. The speed is (theoretically) proportional to the supply voltage V_M, but only as long as the torque is constant. Unfortunately, the equivalent circuit diagram of the DC motor looks like **Figure 2**. The motor winding not only has an inductance L_M, but also an ohmic resistance of the copper wire, which is designated by R_M. The higher the torque, the more voltage drops across R_M, until finally there is no more voltage across the inductance L_M and the motor stops (**Figure 3**).

Control with Tachogenerator or EMF Measurement

To compensate for these torque-dependent speed fluctuations, the motor was once usually coupled to a tachogenerator, which in turn supplied a voltage proportional to the speed (**Figure 4**). However, a motor-tachogenerator unit is larger and more expensive than a tacholess version of a motor.

If the motor is operated with a pulsed voltage (PWM), however, the speed is proportional to the duty cycle. At the same time, the motor operates as a generator in the off-phase of the PWM voltage so that its speed can be measured in this phase. In the past, in the analog age, the electronic effort for such a control was not insignificant, as can be seen from the schematic diagram in **Figure 5**.

A rectangle generator, a voltage-controlled pulse width modulator, a sample-and-hold circuit to measure the actual speed value, and a PI controller were required. In the digital world, the principle remains the same, but the effort required is considerably reduced thanks to the use of a microcontroller.

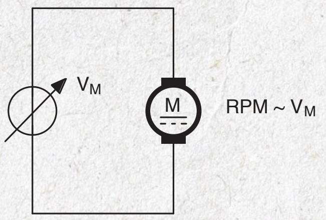


Figure 1: In an ideal world, the speed is proportional to the motor voltage.

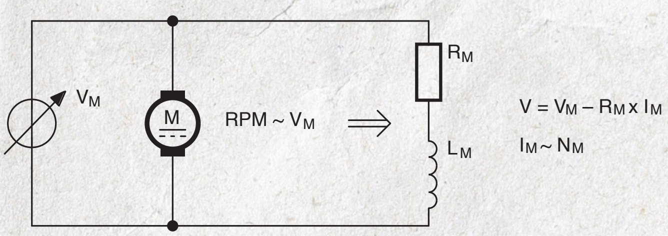


Figure 2: In practice, the ohmic resistance of the motor winding joins its inductance.

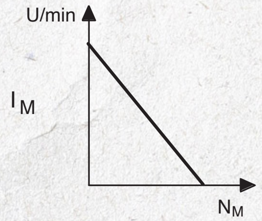


Figure 3: The higher the torque, the slower the motor turns.

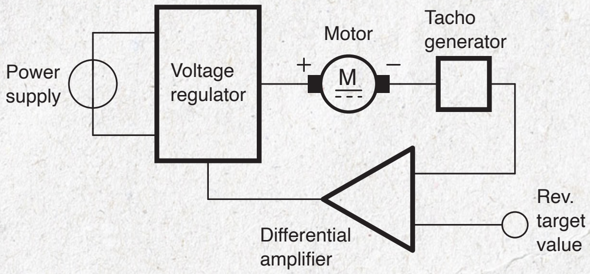


Figure 4: Block diagram of a motor control system with tachogenerator.

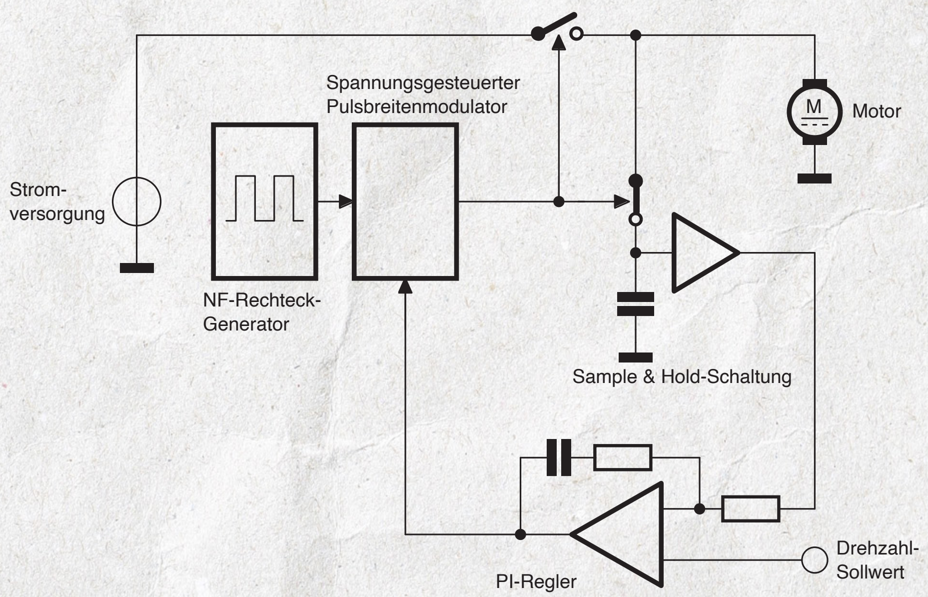


Figure 5: Block diagram of a motor control with EMF measurement.

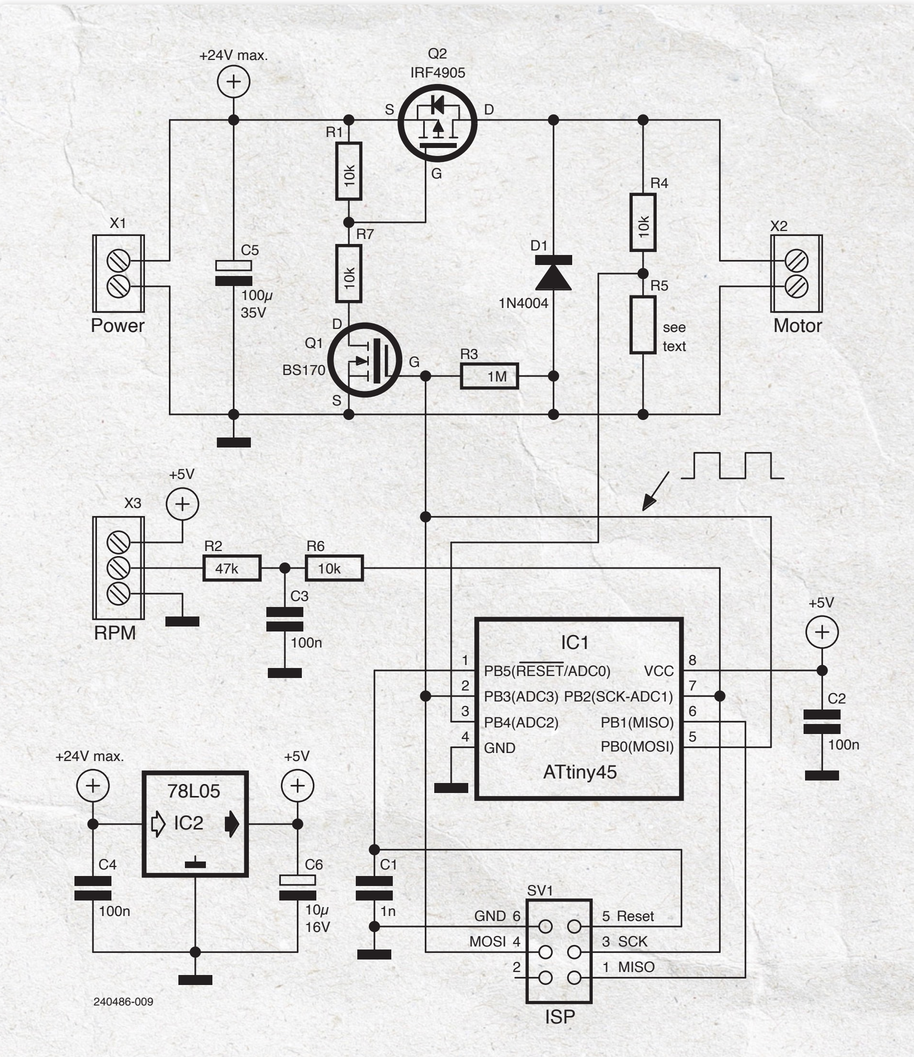


Figure 6: Practical circuit of the EMF motor control.

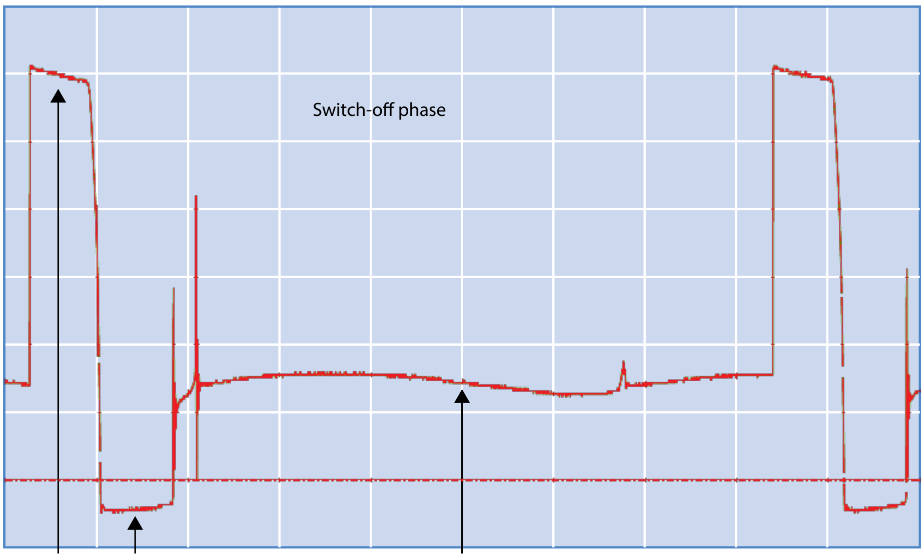


Figure 7: The speed is measured in the switch-off phase after demagnetization.

Practical Implementation of an EMF Control

As the complete circuit diagram in **Figure 6** shows, an ATtiny45 microcontroller from Microchip with 4 kB of flash memory is used for control. The controller has only eight pins, but is perfectly suited for this application. It can be programmed "in system" via SV2 using an ISP programming device.

The microcontroller is supplied with 5 V by the voltage regulator IC2, which is why the input voltage (and thus the motor voltage) must not exceed 24 V. Q1 and Q2 control the motor. Q2 is a PMOS transistor of the type IRF4905, which can theoretically handle a motor current of 74 A, but only if a sufficiently dimensioned heat sink is used. **Figure 7** shows what happens at the motor terminals during the different phases of the PWM signal: After the ON phase of the PWM signal, a demagnetization period follows in the OFF phase; then the motor generates an EMF voltage that is proportional to the speed. This voltage is fed to the ADC2 analog-to-digital converter of the microcontroller via the R4/R5 voltage divider. R5 should be dimensioned so that the voltage at ADC2 does not exceed 5 V.

VB	R5
12 V	4k7
24 V	2k2

The setpoint speed, which is set by the RPM potentiometer or an external voltage of 0...5 V at X6, is sent to ADC1 of the microcontroller. Diode D1 is absolutely necessary because when the control voltage is switched off, the inductance of the motor discharges, which results in a negative voltage spike that D1 limits to about 0.7 V. **Figure 8** shows a suggested printed circuit board layout for the motor control with EMF measurement; the required components are listed in the **Component List**.

Software I

The software for the ATtiny45 was written in BASCOM. The controller is operated internally at 8 MHz. Timer0 is operated as a PWM timer in *Phase Correct PWM Timer* mode.

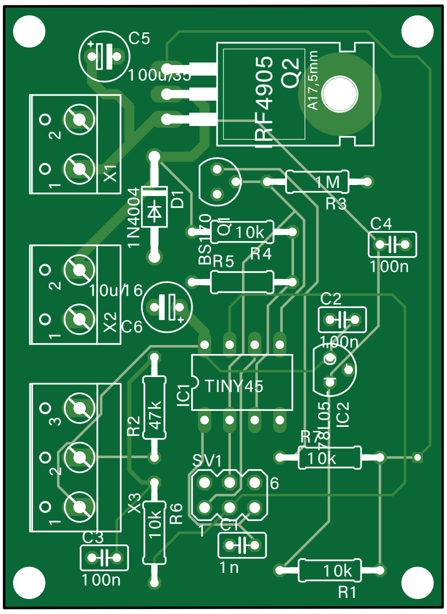


Figure 8: Proposal for a circuit board layout for the EMF control.

With a prescaler of N = 64, the PWM frequency is:

$$f_{OCnxPCPWM} = \frac{f_{clk\_I/O}}{N \times 510}$$

At 8 MHz, this results in a frequency of 245 Hz. The pulse width is set via register PWM0A from 0 to 255.

Depending on the motor type, the prescaler may need to be set to 256, for example if the induction phase is longer than or the same length as the switch-off phase. This results in a PWM frequency of approximately 60 Hz.

In the main program loop, the speed setpoint is constantly read in at ADC1. The actual value is read in at ADC2 during the off-phase (`Pwm_Pin=0`) and summed up. When the motor is switched on again, the average of the actual value is calculated.

To implement the PI controller, there is the constant T_i (integration time), together with the time constant of Timer1 and Kp (proportional gain), which must be adapted to the motor used. The interrupt time of Timer1 is set using the TCCR1 register:

TCCR1	Timer1 Interrupt
4	250 µs
5	500 µs
6	1 ms
7	2 ms

When T_i has expired (Timer1-Interrupt × T_i), the speed deviation is calculated, added to the previous value (taking into account the sign) and multiplied by Kp. The result is output directly as the new switch-on duration.

Control Using RI Compensation

Another practical solution can be what is known as RI compensation. As mentioned at the beginning, the speed fluctuation of a DC motor is due to the ohmic resistance of its copper winding. If the current through the motor is measured, this resistance can be compensated. To do this, only the coil resistance of the motor needs to be known, which can be easily measured.

The circuit in **Figure 9** is similar to that in Figure 6, except that the motor current is measured as a voltage drop across R5. R5 is to be dimensioned so that a maximum of 0.5 V is dropped across R5 at maximum motor current. The power dissipation in watts must be equal to R5 × motor current squared. **Figure 10** shows a suggested layout for the motor control with RI compensation.

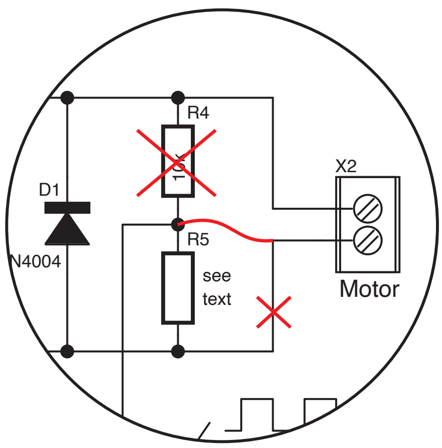


Figure 9: The motor control with RI compensation differs only in one detail.

Software II

The software for the RI compensation is also written in BASCOM. Timer0 is configured as a PWM timer with a frequency of 245 Hz. In contrast to the EMF control, the control here is designed as a pure P controller. To do this, the coil resistance of the motor and the supply voltage must be known and specified as constants `RM` and `U0` in the program.

The motor current is now measured during the switch-on phase of the PWM signal. The effective value of the current is calculated from the switch-on duration:

$$I_{RMS} = I_P \times \frac{T_{on}}{T} = \frac{V_{R5}}{R5} \times \frac{PMW0A}{255}$$

The duty cycle is then increased by the corresponding value.

Two Options

There are several ways to control a DC motor without a tachogenerator. Each of these options has different advantages and disadvantages:

- For the EMF control, a PI controller is required, the parameters of which

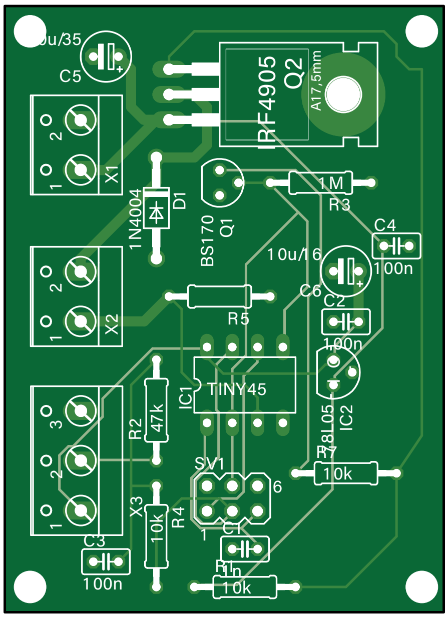


Figure 10: Proposed circuit board layout for the control with RI compensation.

must be adapted to the motor used in order to optimize over- and under-shoot. To do this, voltage fluctuations in the supply voltage are compensated.
- With RI compensation, there are no overshoots or undershoots, but voltage fluctuations in the supply voltage are not compensated.

The schematics, layouts, and software for both controllers can be downloaded from the Elektor Labs project page at [1].

Translated by Jörg Starkmuth — 200486-01

About the Author

Rainer Schuster's fascination with electronics began at the age of 13, when he received the Philips EE1 electronics experiment kit from his parents for Christmas in 1970. In September 1971, he bought his first issue of Elektor magazine and has remained loyal to it to this day. After studying electrical engineering at the Munich University of Applied Sciences, he worked for 37 years as an engineer in electronics development at Agfa in Munich. He has been writing articles for Elektor since 2009. Now that he is retired, he also has his own YouTube channel (www.youtube.com/@rainerschuster5722), where he posts his projects.

Questions or Comments?

Do you have questions or comments about this article? Email the author at rainerschuster@mnet-mail.de, or contact Elektor at editor@elektor.com.

Component List for RI Compensation Controller

Resistors:
R1, R6, R7 = 10 kΩ
R2 = 47 kΩ
R3 = 1 MΩ
R5 = see text

Capacitors:
C1 = 1 nF
C2...C4 = 100 nF
C5 = 100 µF/35 V
C6 = 10 µ/16 V

Semiconductors:
D1 = 1N4004
Q1 = BS170
Q2 = IRF4905
IC1 = ATtiny45
IC2 = 78L05

Miscellaneous:
SV1 = 2 × 3-pin header
X1,X2 = 2-pin PCB terminal, 5 mm pitch
X3 = 3-pin PCB terminal, 5 mm pitch

Component List for EMF Controller

Resistors:
R1, R4, R6, R7 = 10 kΩ
R2 = 47 kΩ
R3 = 1 MΩ
R5 = see text

Capacitors:
C1 = 1 nF
C2...C4 = 100 nF
C5 = 100 µF/35 V
C6 = 10 µF/16 V

Semiconductors:
D1 = 1N4004
Q1 = BS170
Q2 = IRF4905
IC1 = ATtiny45
IC2 = 78L05

Miscellaneous:
SV1 = 2 × 3-pin header
X1, X2 = 2-pin PCB terminal, 5 mm pitch
X3 = 3-pin PCB terminal, 5 mm pitch

WEB LINKS

[1] Elektor Labs page about this project: https://tinyurl.com/200486-01
[2] YouTube video: https://www.youtube.com/watch?v=6IEVBQyKIF4

8-Bit Companion for the Raspberry Pi

Power Saving Made Easy

By Tam Hanna (Hungary)

Raspberry Pis and other SBCs are ideal for sophisticated process control, but require significantly more power than microcontrollers. Why not combine the best of both worlds? Here we show you how to get an 8-bit PIC to switch on a Raspberry Pi whenever it is needed.

Single-board computers with Unix capability facilitate the development of complex control systems. Especially in scenarios with high demands on GUI and data processing, they are superior to microcontrollers (MCUs). Unfortunately, power consumption and real-time capability leave some room for improvement. But why not combine the best of both worlds? If you want to trim an off-the-shelf single-board computer to be economical, you can achieve this with an eight-bitter as a partner. As an example, we want to implement a system that adheres to programmed downtimes and carries out an "alarm start" in response to a specific external event.

The Circuit Concept

In principle, the circuit works as shown in the flowchart (**Figure 1**). The voltage regulator acting as the main supply for the process computer (usually a switching regulator) is controlled by the microcontroller via its Enable input (EN).

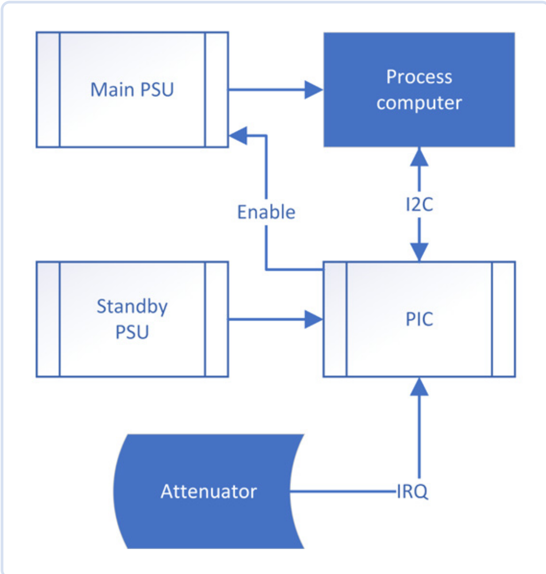


Figure 1: This circuit design significantly reduces energy consumption in stand-by mode.

The MCU obviously requires a separate power supply that is independent of the EN input; due to the low-energy requirement, a linear regulator is the most economical solution here. In general, the concept is completely component-agnostic; the author likes to use modern PIC16F derivatives from Microchip.

Figure 2 shows the sub-circuit that informs the PIC when the SBC (OPI = Orange Pi) is supplied by the external switching regulator (EXT). D1a, R9 and D7a implement a more or less "classic" attenuator, which breaks down input voltages in the range of up to 20 V to a value that is "manageable" for the inputs of process computer and microcontroller.

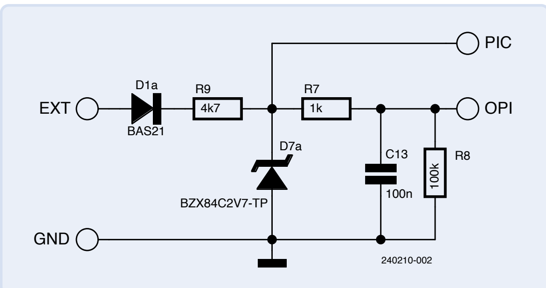


Figure 2: The R7 resistor can save both costs and headaches.

Splitting the series resistor into the values R7 and R9 is necessary because single board computers sometimes become a low-impedance load or have a residual voltage when they are switched off — without the resistor, this would cause the power management microcontroller (connected via the PIC terminal) to see strange or invalid values.

R7 is an additional protective element — the inputs of the process computer are connected to the supply voltage and ground via protective diodes. When very high voltage levels occur, R7 ensures that the current flowing into these diodes is limited and the process computer is not damaged — C13 and R8 provide a small additional debouncing function.

It should be noted that the circuit shown here with its EXT input was connected "directly" to the vehicle electrical system in various school buses. As there are now several thousands of such systems on the market without failures, it has been proven to work.

The role of diode D1a as reverse polarity protection is also helpful — please believe the author, who also works in the logistics sector, that connecting batteries the wrong way round is one of the classic "sports" of a mechanic.

The Software Is the Key

Communication via I²C is generally unproblematic (but don't forget the necessary pull-ups). The "secret" of this system lies in the software. The PIC implements a kind of state machine that is based on the states shown in **Figure 3**.

The implementation of the shutdown process is of particular importance. Unixoid operating systems tend not to react very kindly to rough shutdowns. A convenient and practical way to solve the problem is to implement a countdown timer: The SBC activates this countdown and then starts the shutdown of the operating system. After the (generously dimensioned) period of time has elapsed, the process computer is "inertialized" and can be disconnected from the power supply.

Of course, the PIC can also perform other tasks. In addition to storing serial numbers and other information (in order to make it harder to manipulate), it is also possible, for example, to perform basic control tasks on the PIC. Of course, more complex implementations are also possible: A complex MSR task, for example, would make a 32-bit MCU appear reasonable as the secondary controller.

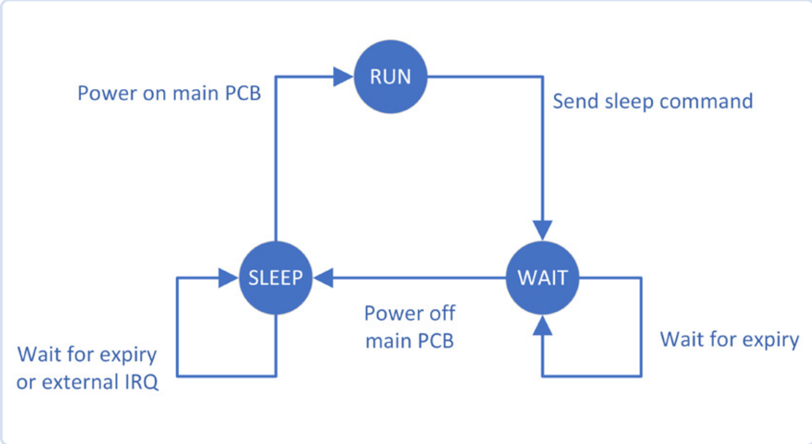


Figure 3: Also helpful in the embedded sector: the state machine.

Practical Experience

Trackers based on the circuit concept shown here are now being used in tens of thousands by one of the author's customers, demonstrating the practical value of the design. Instead of a stand-by power consumption of around 200 mA, the system now gets by with just a few milliamperes. The author's AN4121, published by Microchip, is available at [1] and provides further information on the topic.

Translated by Jörg Starkmuth — 240210-01

Questions or Comments?

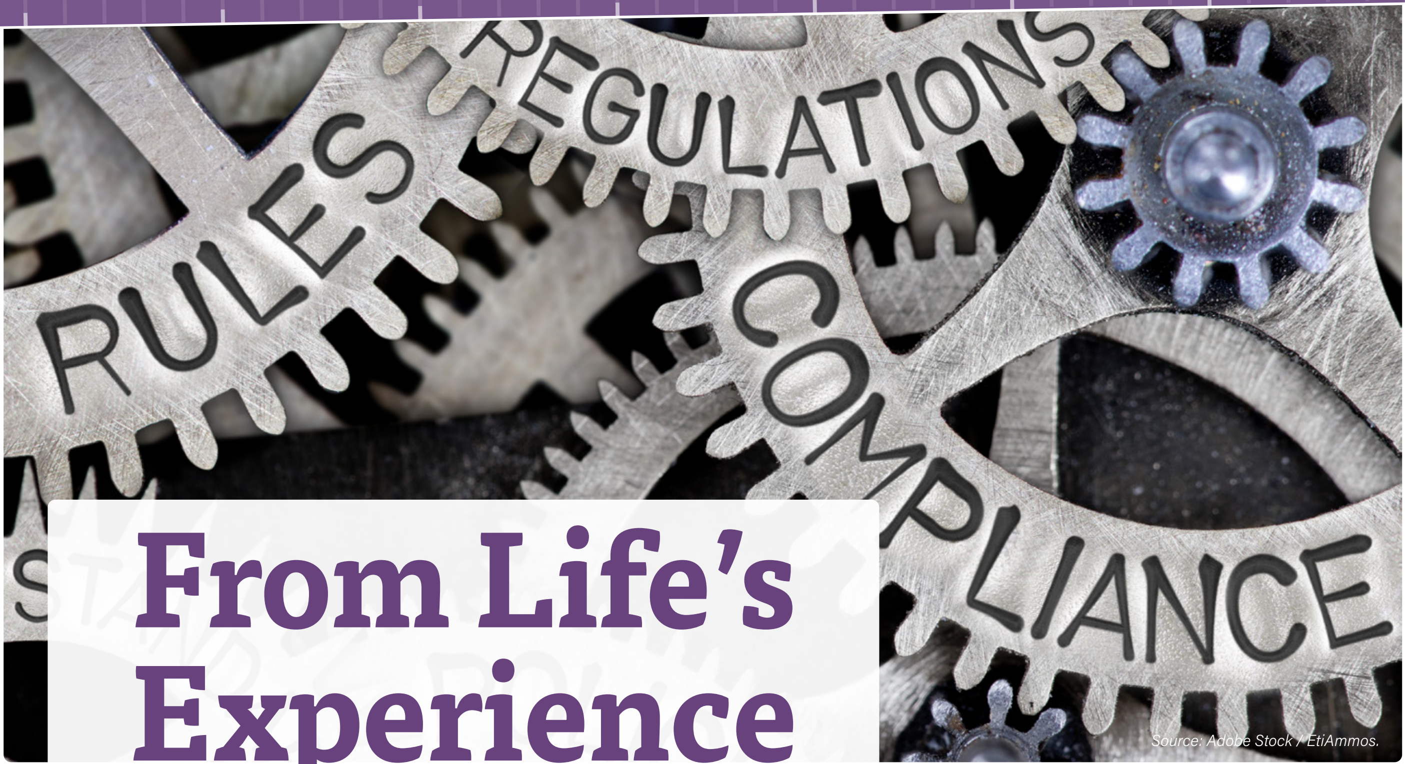
Do you have questions or comments about this article? Email the author at tamhan@tamoggemon.com or contact Elektor at editor@elektor.com.

About the Author

Ing. Tam Hanna has been working with electronics, computers, and software for more than 20 years; he is a freelance developer, book author, and journalist (www.instagram.com/tam.hanna). In his spare time, Tam's interests include 3D printing and the distribution of cigars.

WEB LINK

[1] Usha Ganesh and Tam Hanna, "Using PIC16F Microcontrollers for System Power Supply Control," Microchip Application Note AN4121, 2021: https://www.microchip.com/en-us/application-notes/an4121



Source: Adobe Stock / EtiAmmos.

From Life's Experience

Micromanagement

By Ilse Joostens (Belgium)

I have read with interest the Elektor articles from 2021 and 2024 on balcony PV installations by Dr. Thomas Scherer [1] [2], and I am entirely convinced by the idea of covering your home's "quiescent power consumption" with solar energy. In Germany, you even get a subsidy for this; but unfortunately, I live in Belgium where this kind of installation is strictly forbidden by Synergrid technical regulation C10/11 due to — alleged — fire and electrocution danger.

Belgians are rather risk-avoiding, and this is also reflected at the policy and regulatory level. In my opinion, it would be better to ban extension cords with a power strip, electric bikes, electric scooters and hoverboards. These have been in the news several times in the context of house fires and with the last two devices, you can have serious accidents too. I was reminded of this after last summer's commotion around a well-known Belgian DIY store that had offered plug-in solar panels with the best of intentions but had to remove them from its shelves again, to its shame.

Speed Camera

While in neighbouring countries "plug-in solar panels" have been used trouble-free for years (**Figure 1**), a Belgian user organization and sector federation for renewable energy ODE — apart from the fact that it is forbidden — seem to be particularly disliking of balcony PV installations [3]. According to them, these are potentially unsafe, which may have a short lifespan, and hardly financially interesting. They have a clear preference for larger PV installations, including for flat dwellers. The latter should just install a communal installation on the roof or engage in energy sharing with the owner of an installation at another location. For a communal installation, you need a two-thirds majority of the co-owners, good luck with that, I would say; as a tenant, you should try to convince your landlord eventually. And regarding energy sharing, that is hardly appealing because it is complex, cumbersome and above all expensive. It is possible to have a small PV installation in Belgium, but you have to follow the same procedures as for traditional larger installations. With a fixed connection to a separate group in the distribution cabinet, the necessary inspections and bureaucracy, the costs rise considerably, and your profits melt like snow in the sun.

However, there is light at the end of the tunnel and from May 2025, plug-in solar panels would — finally — be allowed in Belgium after all. The question, of course, is how strict the conditions and modalities will be. With a bit of bad luck, you will have to be able to present an inspection report of your electrical installation, and you run the risk of having a "smart" meter shoved down your throat.

Figure 1: Balcony PV power plant — banned in one country, subsidized in another. Source: Adobe Stock / Ronald Rampsch.

Figure 2: Even large companies once started small. Source: Adobe Stock / Gorodenkoff.

That smart meter hasn't been out of the news recently, first because of the virtual rollback or not for solar panel owners and later in the context of the introduction of the capacity tariff. With that tariff, your smart meter becomes more like a speed camera that mercilessly charges you every time you have a few too many devices powered on at once in a moment of inattention.

And the regulation on the roll-back counter, from which owners with solar panels could benefit for another 15 years, was rejected by the Constitutional Court in 2021 because the Flemish government had gone beyond its authority. After fierce protests, the same government was obliged to compensate the duped owners of solar panels.

Flipflop

You will no doubt be familiar with mathematician and computer scientist Edsger Dijkstra [4] who took issue with the excessive use of `goto` instructions in higher programming languages [5]. During my training, the ban on `goto` instructions was enforced to avoid an untidy "spaghetti code." Politicians usually have a legal background and within that education one apparently sees no point in ill-considered ad hoc legislation. They just act according to the delusion of the day or based on flash politics, resulting in unclear "flip-flop legislation." Premiums for electric cars have already been introduced and abolished twice, and because of twists and turns in the law, users of electric company cars who charge them at home will soon be allowed to pay a lot more taxes. Belgium does not have a monopoly on absurdities, and in the Netherlands I hear rumours about grid operators secretly increasing the voltage taps on district transformers to limit feed-in from solar panels. In Zeeland, an experiment has even started where homeowners are asked to switch off their solar panels on sunny days for a fee. It shouldn't get any crazier after years of pushing people to install solar panels anyway.

Patronizing

The government is increasingly interfering in all aspects of our lives, and unfortunately this goes beyond energy, our home, heating systems and which car we drive. Similarly, the sale of numerous "hazardous" substances to individuals has been restricted. Even lead-based solder is becoming harder and harder to find, and there are already suppliers in Europe that no longer sell this stuff to individuals because it contains lead. Just imagine working on older electronic equipment for the hobby. This kind of micromanagement also curtails entrepreneurship because many companies start small, perhaps as a few students who have discovered a gap in the market and are working on a product in a garage (**Figure 2**). Even giants like Microsoft, Google [6], HP and Amazon once started this way [7].

The website "Nanny State Index" [8] charts the patronization by various governments when it comes to eating, drinking, smoking, and vaping and, as far as I am concerned, may be expanded to include more criteria. I dare to plead for less interference, fewer and clearer regulations and, above all, more juridical certainty. Nobody can be against that.

Translated by Hans Adams — 240608-01

WEB LINKS

[1] Dr. Thomas Scherer, "Balcony Power Plant," Elektor 9-10/2021: https://www.elektormagazine.com/magazine/elektor-183/59831
[2] Dr. Thomas Scherer, "Optimizing Balcony Power Plants," Elektor 1-2/2024: https://www.elektormagazine.com/magazine/elektor-324/62631
[3] VRT nws: Are solar panels on your balcony a good idea?: https://www.vrt.be/vrtnws/en/2022/10/18/are-solar-panels-on-your-balcony-a-good-idea/
[4] Wikipedia: Edsger Dijkstra: https://en.wikipedia.org/wiki/Edsger_W._Dijkstra
[5] Mathematics & Computer Science Centre: Edsger Dijkstra: Go To Statement Considered Harmful: https://homepages.cwi.nl/~storm/teaching/reader/Dijkstra68.pdf
[6] Inside Google's original garage, 1998-style: https://blog.google/products/maps/inside-googles-original-garage-1998-style/
[7] Business Pundit: 11 famous garage startups that now rule the world: https://www.businesspundit.com/11-famous-garage-startups-that-rule-the-world/
[8] The Nanny State Index: https://nannystateindex.org/

PECULIAR PARTS THE SERIES

Mercury Rectifiers

By David Ashton (Australia)

Before the advent of high-power semiconductor-based rectifiers, transforming alternating current to DC in industrial and transportation fields was no mean task! The devices were huge, fragile, contained highly polluting materials, and required frequent maintenance.

Rectifiers — those are like diodes, right? Well, yes. But these are not the kind of diodes you'd use in your crystal radio. Or even for your Raspberry Pi power supply. Or even for that super-duper 200 W per channel amplifier you've been building. Think electric trains, subway systems, broadcast transmitters. BIG stuff. As Crocodile Dundee might say, "That's not a rectifier, THIS is a rectifier!"

Liquid Mercury

Mercury-Arc rectifiers make use of the fact that if a pool of liquid mercury with some mercury vapor is used as a cathode, an arc can be drawn from a carbon anode above it, but the process does not work the other way around.

Hence, rectification. This is sufficiently electronic to justify their inclusion in this column, even though they're not the kind of component that's ever been used in an Elektor project.

Mercury-arc rectifiers were invented in 1902 by Peter Cooper Hewitt, an American electrical engineer who had invented mercury vapor lamps (the forerunners of our fluorescent lamps) in 1901. They were developed in the early 1900s and rapidly became the go-to solution for high-voltage, high current rectification. The arc voltage is around 20...30 V, and the simplicity of their construction makes them efficient and reliable. They were used up to the 1970s, when semiconductor rectifiers and thyristors that were up to the same job became available. Some were used until 2012. A typical 6-phase rectifier operating is shown in **Figure 1**.

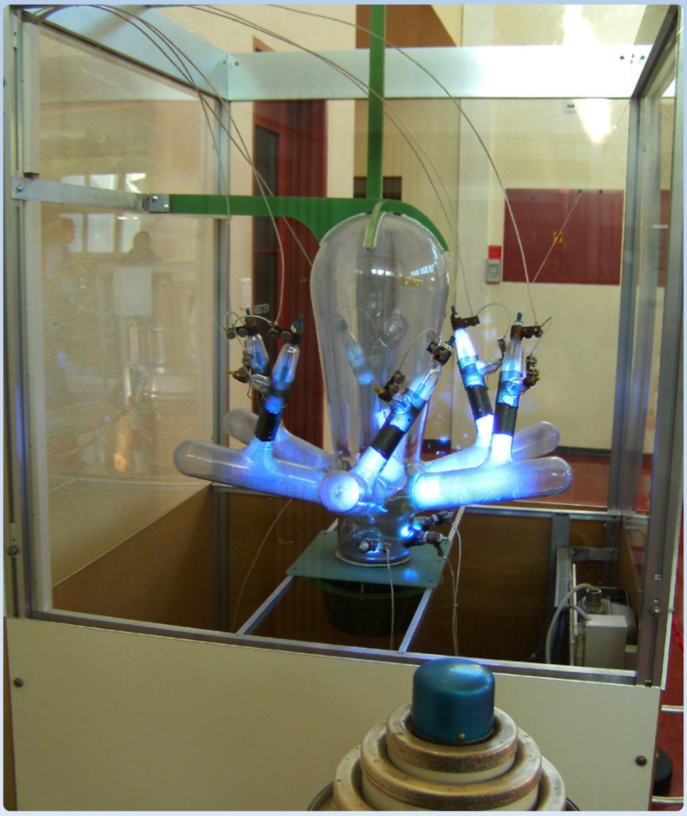


Figure 1: A 6-phase, high-power mercury-arc rectifying tube at work. (Source: Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Quecksilberdampfgleichrichter_in_Betrieb.JPG)

Ignitor Electrode

Ignition has to be started by an ignitor electrode, which usually has to briefly come into contact with the mercury. This is done by a number of means, including electromagnets, bimetallic strips, etc. Once the arc has been struck to cause mercury vapor to form, rectification can take place.

Most mercury-arc rectifiers were 3 or 6-phase, but single-phase rectifiers needed an excitation electrode to keep the process going. The whole assembly is built within a large glass bulb, which allows the

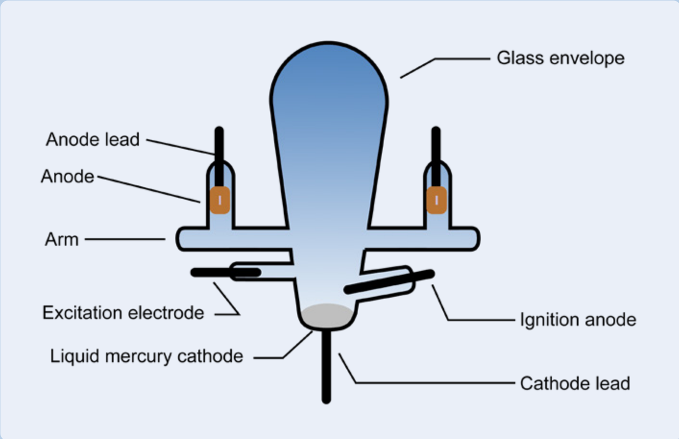


Figure 2: Functional schematic of a mercury-arc rectifying tube (Source: Wikimedia commons, https://commons.wikimedia.org/w/index.php?curid=4577899)

mercury vapor to condense and flow back to the cathode pool. The construction of a typical rectifier is shown in **Figure 2**.

A typical 6-phase, 150 A rectifier was around 600 mm tall and about 300 mm round. Above 500 A steel tanks were used with ceramic insulators for the electrodes, and these were rated up to several thousand amps. Ratings up to several kV were available, higher with special construction techniques, but these required frequent maintenance.

The mercury arcs emit a lot of ultraviolet light, you could get sunburned while working around them. Additionally, the noise from them and the associated transformers was considerable. Mercury is highly toxic and extensive clean-up work is often needed to remove traces of mercury when decommissioning them.

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Questions or Comments?

If you have technical questions or comments about this article, feel free to contact the Elektor editorial team by email at editor@elektor.com.

About the Author

David Ashton was born in London, grew up in Rhodesia (now Zimbabwe), lived and worked in Zimbabwe, and now lives in Australia. He has been interested in electronics since he was "knee-high to a grasshopper." Rhodesia was not the center of the electronics universe, so adapting, substituting, and scrounging components were skills he acquired early (and still prides himself on). He has run an electronics lab, but has worked mainly in telecommunications.

Elektor infographic

Power and Energy

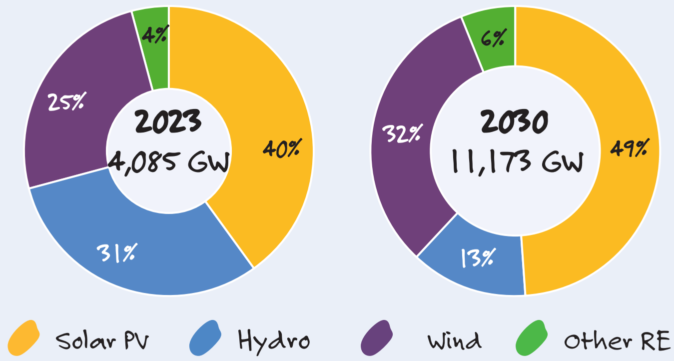
Global Solar Market: A Bright Outlook to 2030

The global solar energy market is on a positive growth trajectory as the solar energy industry is in a constant state of evolution. By 2030, installed renewable electricity generation capacity under the IRENA 1.5°C Scenario (see textbox on next page) is expected to more than double, with solar PV contributing 49% of the total capacity compared to 40% in 2023 [1]. This translates to an increase from 4,085 GW in 2023 to 11,173 GW by 2030, driven by annual additions averaging 558 GW per year.

Challenges and Opportunities

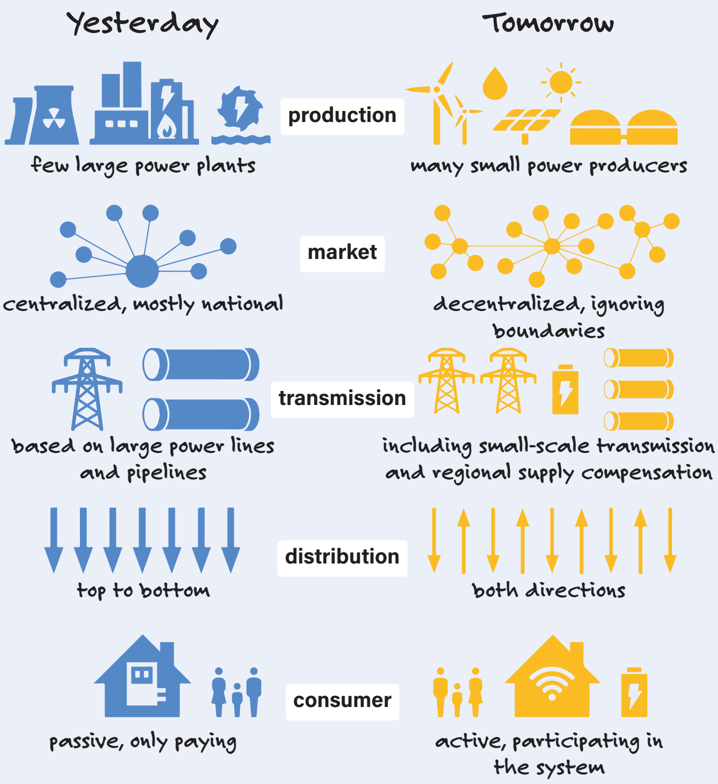
Achieving the 2030 targets will require robust innovation and investment. The solar sector's ability to sustain its current momentum hinges on continued advancements in technologies like bifacial panels, floating solar farms, and AI-optimized energy systems. These innovations will enhance efficiency and integration, ensuring solar's key role in a clean energy future.

Global Installed Renewable Electricity Generation Capacity in the 1.5°C Scenario, 2023 and 2030 [1].



Source: SolarPower Europe (2024), IRENA (2024)

Smart Grids: Enabling the Energy Transition



Source: Bartz/Stockmar (M), CC BY 4.0

Solar Energy: Innovations Shaping the Future

- Perovskite Solar Cells: These affordable and efficient alternatives to silicon cells are transforming solar accessibility. Lab efficiencies of up to 25% suggest they could become a cornerstone of future solar technologies.
- Transparent Solar Panels: Integrating photovoltaics into windows offers a revolutionary way to harvest energy without compromising aesthetics. Early-stage transparent panels are achieving efficiencies around 10%.
- Floating Solar Farms: By utilizing water surfaces, floating solar farms optimize land use while benefiting from natural cooling, which enhances panel efficiency.
- AI-Optimized Energy Systems: AI is transforming solar operations, helping precise energy prediction, smarter grid integration, and real-time optimization.
- Solar Skins: Customizable appearances for solar panels allow ideal integration into residential and commercial designs, addressing aesthetic concerns [5].

Hydrogen: Main Ingredient for Decarbonization

Another critical enabler has emerged for sectors that are challenging to electrify, such as heavy industry and long-haul transport, and that one is hydrogen. According to IRENA, hydrogen could fulfill 12% of global energy demand under the 1.5°C Scenario [3], with applications spanning transport, power generation, and heating.

However, its production methods vary widely in environmental impact, earning the labels grey, blue, and green depending on the CO_2 emissions involved. Currently, 96% of global hydrogen production relies on fossil fuels (grey hydrogen), underscoring the need for a rapid transition to cleaner methods [4]. The high costs of production for green hydrogen, and substantial energy losses during production, storage, and conversion make it less efficient than alternatives like batteries, while increasing blue hydrogen depends on costly carbon capture technologies.

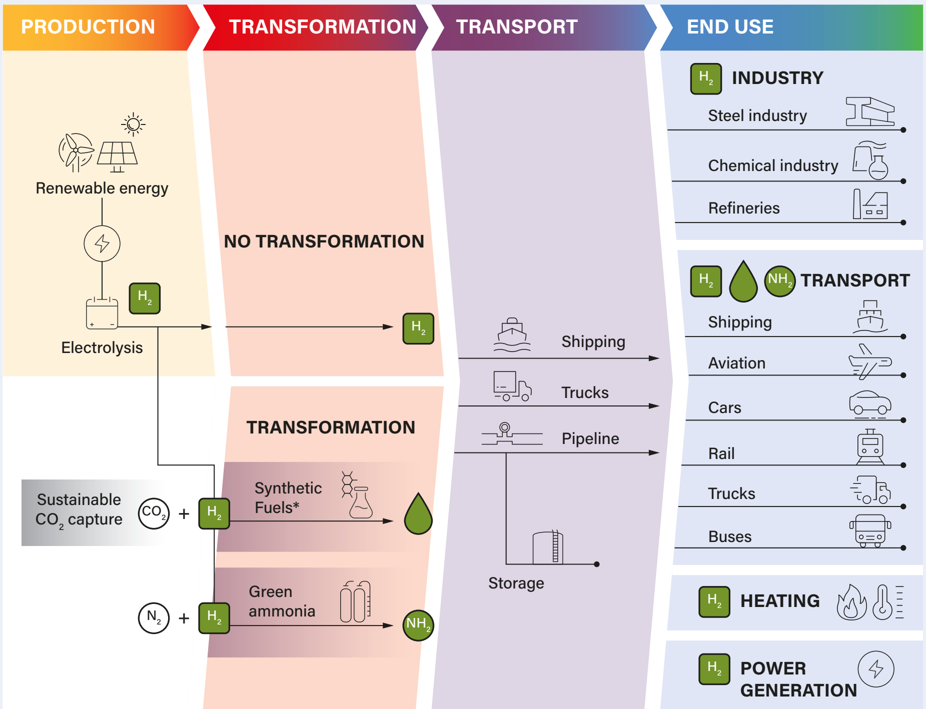
12%

of global energy demand could be fulfilled by hydrogen under the 1.5°C Scenario.

96%

of current share of hydrogen is produced from fossil fuels (grey hydrogen).

Green hydrogen production, conversion, and end uses. [3]



What Is IRENA's 1.5°C Scenario?

IRENA stands for the International Renewable Energy Agency, an intergovernmental organization that promotes the adoption and sustainable use of renewable energy worldwide. The IRENA 1.5°C Scenario in the World Energy Transitions Outlook presents a pathway to achieve the 1.5°C climate target by 2050 [2]. Achieving this target requires substantial investments in clean energy technologies, such as solar, wind, and storage, to decarbonize global energy systems.

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WEB LINKS

[1] SolarPower Europe, "Global Market Outlook," June 2024: https://tinyurl.com/solar-outlook-2024

[2] IRENA, "World Energy Transitions Outlook 2024: 1.5°C Pathway," November 2024: https://www.irena.org/Publications/2024/Nov/World-Energy-Transitions-Outlook-2024

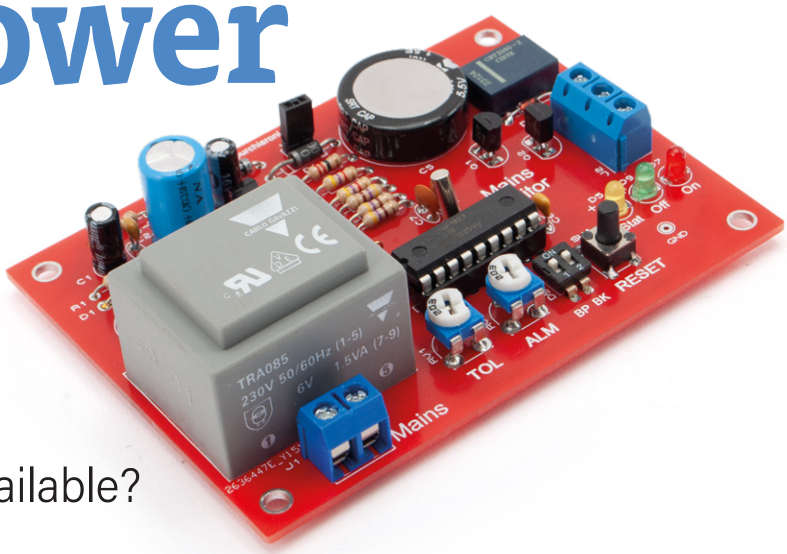
[3] IRENA, Hydrogen: https://www.irena.org/Energy-Transition/Technology/Hydrogen

[4] Zurich, "How blue and green hydrogen can help solve the climate crisis," July 2024: https://www.zurich.com/media/magazine/2022/is-hydrogen-the-fuel-that-can-save-our-planet

[5] Tamesol, "The Future of Solar Energy," January 2024: https://tamesol.com/future-of-solar-energy/

Elettronica In
www.elettronicain.it

Mains Power Outages Monitor



Is Your Grid Supply Steadily Available?

By Stefano Purchiaroni (Italy)

In areas where mains power is unstable and/or there may be safety issues, it may be useful to have a circuit that constantly monitors its presence and signals the outages in a timely manner to an external system. In this article, two design solutions are presented: one basic analog and a digital, microcontroller-based version, to monitor the presence of the power grid voltage at home and also perform the outages count.

This design addresses the need to monitor service interruptions, whether caused by technical issues — such as infrastructure maintenance — or by malicious intruders tampering with the external meter switch to disconnect the power supply. Such an action could deplete the alarm system's backup batteries, leaving the home vulnerable. Triggering an alarm as soon as a disconnection is detected enhances overall home security.

To prevent unnecessary activations, a delay (or tolerance) time of a few seconds has been implemented. This helps avoid false alarms caused by brief interruptions. In addition to the basic version (see **Table 1**), the digital version offers enhanced features: it tracks mains voltage drop events, allows adjustment of alarm and delay times, and automatically deactivates the signal once the preset alarm duration has elapsed. Furthermore, by configuring two DIP switches on the PCB, you can enable a beep function and a power-restoration notification. These additional features will be discussed in detail later.

Table 1: Available Functions in analog and digital Version.

Function	Analog	Digital
Delay (tolerance time) against short interruptions	×	×
Delay time adjustment	-	×
Alarm stop after a preset time	-	×
Alarm time adjustment	-	×
Counting and display of outages number	-	×
Selectable *pulse* or *permanent* activation	×	×
Signaling of mains power return	-	×

Differences Between the Analog and Digital Versions

Analog Version

As can be seen from the diagram in **Figure 1**, the power supply section has no transformer, which we will find in the digital version instead. **Therefore, greater care must be taken during testing, since the whole circuit is connected to the mains voltage, with danger of electrocution in case of contact!** In the case of the digital version, this danger is limited to the small part of the circuit connected to the primary of the transformer, **which nevertheless requires a high level of attention during the testing phases**!

After the AC rectification and 24 V DC limiting section, consisting of diodes D1...D4 diodes and Zener diode D5, we note the split of that voltage source into two leads. One heads to the D6-C2 series, the other goes to the base of Q1. The D6-C2 series network produces a stabilized

23.3 V output, used to activate the relay via path 4-6 (steady mode) of the DPDT switch SW1. When the mains voltage fails, the relay returns to the off position, thus closing the COM-NC contact. Please note: In the circuit diagram, the relay is drawn in its de-energized state, which means the alarm is on. This is valid only when SW1 is in *Steady Mode*, in the position represented on the schematic. In the other position of the switch (4-3/5-2/*Pulse Mode*) the relay gets energized just for 1 to 2 seconds (which means then the alarm is on).

When the mains voltage fails in *Steady Mode*, the alarm is activated with about a 3-to-4-second delay, due to the energy stored by the large electrolytic capacitor C2 being discharged. When power comes back on, the deactivation of the alarm will occur with about a 2 s delay, the time it takes C2 to charge and provide a high enough voltage to activate the relay again.

Capacitor C5, initially discharged, allows the relay to be instantaneously activated at full voltage, but once charged, the current to keep it activated is supplied through R5, and reduced slightly, yet remaining at a level more than enough to hold the relay contacts in the closed position. This technique greatly extends the life of the relay, which remains slightly underpowered most of the time.

The relay should be a DPDT type, with a 24 V coil and an internal resistance of 1,600 Ω. Any mains disconnection that lasts less than the delay time mentioned earlier will not produce an alarm activation, since C2 will not have discharged enough to drop the voltage supplied to the relay below its V_{off}, measured experimentally at around 4 V. This delay avoids unnecessary alarms in case short interruptions might occur.

In this analog version, the delay time is not adjustable. Another down side concerns the alarm time: Once C2 is discharged — and still no mains voltage is present at the input — the relay goes off permanently, leaving the alarm active indefinitely. Management of a maximum time will have to be implemented downstream of the circuit, or it must be part of the siren or other controlled device of choice.

In addition to permanent signaling, the *Pulse Mode* of about 2 s can be selected through the other position of switch SW1 (closed contacts 5-2 and 4-3). In the absence of mains voltage, C3 gradually discharges, reducing the voltage across the base of Q1 until it is brought into conduction. Q1 thus lets current flow from C2 to the relay, passing through C4. The relay is energized, activating the alarm.

After about half a second, C4 is fully charged, reducing the current flow on the relay coil until the relay is de-energized, approximately 2 s later. The values of the capacitors and resistors are already calculated to make sure that the charge of C2 can sustain the whole cycle. When the power returns, Q1 will go off again, the relay will not change its state, and C2 will be charged once more and will be able to support new cycles.

Note the important function of diode D6 in this mode, which acts as a "check valve" preventing the base of Q1 from remaining high due to the accumulated charge in C2, and the relay from staying off.

Digital Version

The digital version's greater complexity is immediately apparent from the schematic in **Figure 2**. The circuit is supplied through a transformer with a 6 V output, which feeds two rectifier bridges, BR1 and BR2. The latter, followed by the stabilization section — consisting of C3, a small, 5 V linear voltage regulator U1 and C4 at the output — provides power for microcontroller U2, a versatile PIC16F1827 by Microchip. In the event of no mains voltage, 1.5 F supercapacitor C5 will continue to provide enough power to the PIC for a considerable time. Management of the supercapacitor is achieved by blocking diodes D2, D3 and D4, which isolate it during ordinary operation but ensure its charge.

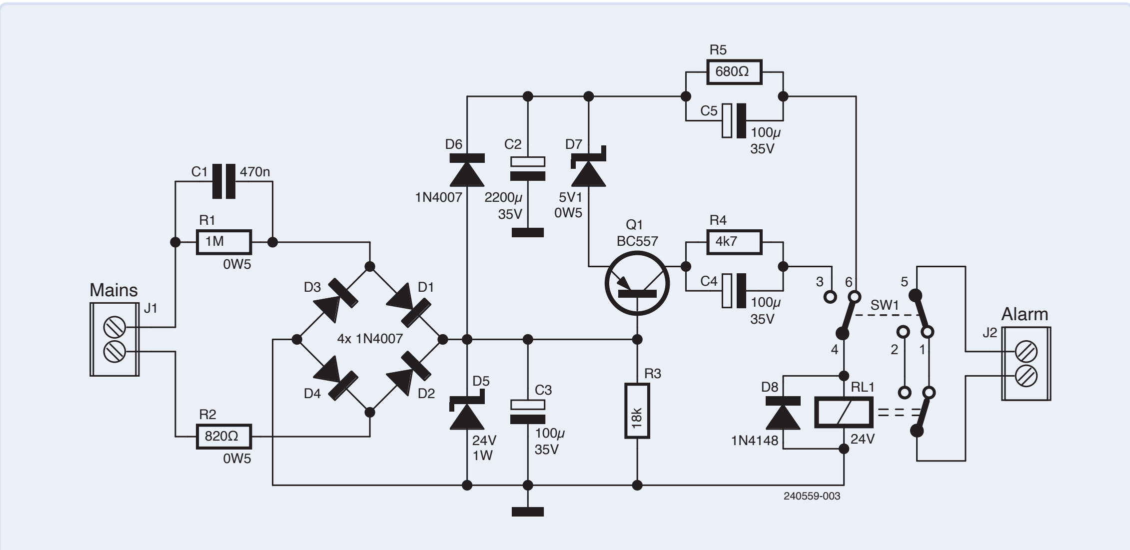


Figure 1: Schematic of the mains power outage analog version.

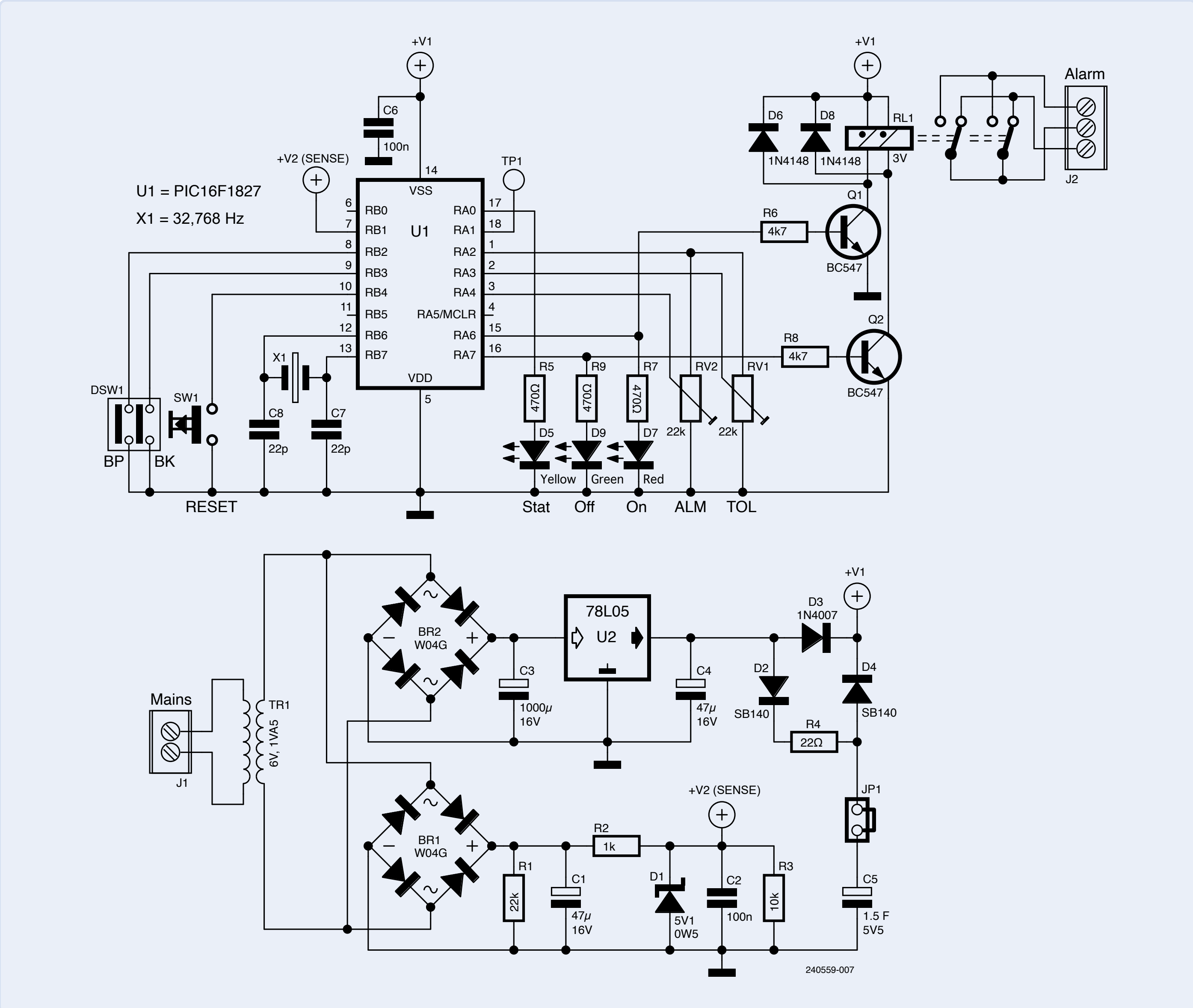


Figure 2: Schematic of the microcontroller-based, digital design.

Note jumper JP1, provided for removing and reprogramming of the PIC without it being powered by the supercapacitor. To avoid excessive voltage drops, diodes D2 and D4 were chosen to be Schottky types, with a direct threshold voltage V_{DS} as little as 0.2 V. This allows C5 to be charged up to 4.8 V, and to get 4.6 V for the backup power supply to the PIC, which has a minimum operating voltage of only 2.8 V for the chosen model.

When the supercapacitor supplies the circuit, the reduction of the microcontroller's power consumption is achieved by software-enabling the "Nanowatt" mode, introduced by Microchip on most of its microcontrollers. It sends the controller into a low-power state, where only the 32,768 Hz oscillator remains on, reactivating the code execution only at the interrupts coming from the timer associated with that oscillator. The interrupts then wake the microcontroller for program execution every second, basically to count the seconds elapsed and decide if it is time to act on the relay — comparing the second counter with the reading of the two resistive trimmers RV1 and RV2.

A further reduction in power consumption is made possible by connecting the hot side of the two trimmers not directly to the supply voltage, but to digital output pin RA2, which will be set to logic high level only during the reading of the two trimmers, taken via analog inputs AN3 and AN4 (pin 2 and 3 of U1, RA3, and RA4, respectively).

Mains voltage drop detection is done by the section starting at BR1, which has no high capacitance downstream, but is equipped with a circuit that generates 5.1 V when mains power is present.

In the event of an outage, the SENSE-tagged output voltage drops quickly, communicating the event to digital input pin RB1 (AN11), which interprets a voltage less than 0.8 V as a binary "0"; with the component values in this section, this threshold is reached about half a second after the mains voltage drop. By mounting optional resistor R3, this delay can be further reduced.

Based on the high or low level of pin RB1, the management software activates the alarm, according to the settings of the two potentiometers RV1 and RV2, which allow you to adjust the delay time between 0…10 s, and the alarm time from 0…2 min.

As mentioned earlier, second-counting is handled by the PIC's internal low-power oscillator, fitted with the small external 32,768 Hz watch crystal, X1. Again, to minimize power consumption, the relay chosen is a bistable, 3 V, double-coil DPDT type. The two sets of contacts are connected in parallel to increase the current carrying capacity, which, however, may not exceed 5 A.

The two turn-on and turn-off coils are driven by Q1 and Q2 transistors, whose bases head to the PIC's RA6 and RA7 pins. The microcontroller will thus be able to turn the relay on and off with short positive pulses on those pins. This chip is also connected to a dual DIP switch, which enables the two optional functions, *Beep* and *Back*.

The former limits the alarm on to about one second, to provide a brief but intense warning to those in the house, for example, alerting them to the voltage drop without disturbing the neighborhood. The *Back* function provides two short pulses to indicate the return of mains voltage. However, this function is limited by the maximum energy delivery time provided by supercapacitor C5, which is about a couple of hours.

Finally, we note button SW1 and LED D5. The latter has the task of using short flashes to indicate the drop events that have occurred. If, for example, a power failure has occurred twice, D5 will cycle two flashes, followed by a pause of about 3 s.

To reset the count, simply press the *Reset* button SW1. This switch also performs a full restart of the PIC, and a forced disable of the relay, which is useful in case of problems. The two LEDs, D7 and D9, indicate the output of the short command to enable and disable the relay, which, if not followed by the clicking sound of the relay, help to identify a failure of this electromechanical component.

Software

Let us focus on the main functions, `SetAlm()`, `interrupt()`, and `main()`. The `SetAlm` function shown below provides for the activation of the alarm device connected to J2 output terminals by direct pulses to the bistable relay. The persistence time of the pulse to the relay control coils is defined by the constant `RlyTim`, currently set to 200 ms. The coils head to pins RA6 and RA7 of the microcontroller, which energizes them through Q1 and Q2 transistors.

```
void SetAlm() {
// Activate the alarm and count the event in EEPROM

// Activate the alarm
  ALMOFF=0;
  ALMON=1;
  delay_ms(RlyTim);
  ALMON=0;
  curs = 0;           // Reset the second counter
}
```

The following `interrupt()` function constitutes the entry-point of the PIC's interrupt service routine, ISR. It is invoked by the interrupt generated by Timer1 when the second expires, even in low-power mode. An output is provided on the circuit board on test point TP1 to verify with a frequency meter or oscilloscope the operation of the oscillator.

TP1's level toggles every second, producing a 0.5 Hz signal. The ground for the measurement is available on the respective GND-labeled test point. The main purpose of the interrupt procedure is to count the elapsed seconds using the 32-bit variable, `curs`. The interrupt for the next cycle is enabled again downstream of the function:

```
void interrupt() {
// Interrupt Service Routine.
// It is called every second by Timer1 overflow.

// --------- TMR1 ---------
// Manage Timer1 overflow (each 1s)
// to count seconds
  if (PIR1.TMR1IF == 1) {
    CLKOUT ^= 1;      // Provide 0.5 Hz to Pin 1
                      // for checks
    curs++;           // Update the current
                      // second counter
    TMR1H = TMR1H_INI; // Reload counter high byte
    TMR1L = TMR1L_INI; // Reload counter low byte
    PIR1.TMR1IF   = 0; // Clear TMR1 Interrupt flag
  }
}
```

After hardware setup and initialization of variables, `main()` function handles events according to the logic of a finite-state automaton. The current state of the automaton is set in the `Mode` variable. First, pressing on the SW1 button is verified, to reset the event counter and for restarting the microcontroller via the `reset` assembler instruction.

At the first power-up with a blank microcontroller, and only then, it will be necessary to press the SW1 button to set the alarm count in EEPROM to zero. At the execution of `setup()`, following the button press, it will also be forced to turn off the alarm control relay, in case (for any reason) it had remained active.

Alarm activation events are counted in the `AlmCnt` variable. Note that — in case the return of mains voltage is very late and the capacity to support operations provided by supercapacitor C5 is exceeded — in order not to lose the alarm count, the value of `AlmCnt` is saved in EEPROM. The `setup()` function requires it to be read again when the microcontroller is restarted:

```
void main() {

  setup();         // Initialization

  while(1) {        // Forever Loop

  if (Button(&PORTB,4,1,0)){
       // Reset button pressed
    STSLED = 1;
    Delay_ms(500);
    STSLED = 0;
    AlmCnt = 0;
    EEPROM_Write(CNTADDR, AlmCnt);
    // Raz the Alarms counter in EEPROM
    curms = 0;
    // Raz the elapsed ms for Blink cycle
    BlkSts = 0; // Reset the Blink automaton
    {asm{reset}};   // Reset the MCU
               // (the program will restart)
  }
```

In the following excerpt, the voltages on the analog pins connected to the slider of the two resistive trimmers are read; they are dedicated to adjusting the delay and alarm times. The reading is made possible by activating the hot side of the two trimmers via the digital output pin RA2, referred to here as `DIVPOW`.

Since the microcontroller has a 10-bit A/D converter, the two readings will consist of a value between 0 and 1,023, between limits defined by configurable parameters that by default limit the delay time to between 0...10 seconds, and the alarm time to between 0...2 minutes.

In default state `Mode_SBY`, managed by the block that follows, the automaton waits for the mains voltage drop event, communicated by the SENSE line through pin RB1 (AN11) referred to here using the `POWER` definition. If it goes to logic level 0, then second-counting will start, setting the PIC to low-power mode. Please keep in mind that from then on, power is provided solely by supercapacitor C5.

The new state is `Mode_TOL`:

```
// Automaton
switch (Mode) {
  case Mode_SBY:  // Nominal Mode.
                 // Wait for a Power Down event

if (POWER == 0) {  // The Main power gone down,
      // the MCU is powered just by supercap!
    curs = 0;       // Start seconds count
    STSLED = 0;     // Force Ststus Led off
    Mode = Mode_TOL;
        // Enter the Tolerance Mode
  }
  break;
```

In the `Mode_TOL` state handled by the following section, one of two possible events is awaited: the return of mains voltage before the delay time expires, to return again to the `Mode_SBY` state, or the overrun of that time.

The condition to be met for the latter case is slightly complicated by the management of the optional ***Beep*** mode activated via the first of the two DIP switches. Depending on the state of this switch, either the `ttol` limit time defined first by the RV1 trimmer reading, or the `MinTol` time set by the initial code definitions, corresponding to 2 s, will be selected. Exceeding the limit time brings the automaton into the `Mode_ALM` state.

The continuation of the code is always bound to the Timer1 interrupt, since it continues to operate in low-power mode:

```
case Mode_TOL:     // Waiting ttol time
// before activating the alarm

  if (POWER == 1) {   // Mains is back
           // before the alarm activation
    Mode = Mode_SBY; // Just go
                    // back to Standby Mode
  } else {            // Check end
                    // of Tolerance time
    if ( ((BeepMode==FALSE)&&(curs>=ttol))
    ||((BeepMode==TRUE)&&(curs>=MinTol)) ) {
      SetAlm();            // Start the
                          // alarm,
      IncAlm();            // Increment
                          // the alarms counter,
      Mode = Mode_ALM;     // Enter in
                          // the Alarm Mode
    }
  }
  break;
```

This part handles the `Mode_ALM` state. It waits for the mains voltage to return, to reset the alarm and return to Standby by permanently exiting the low-power mode. Or one waits for the exhalation of the maximum alarm time, chosen from the `talm` value set by the analog reading of the RV2 trimmer, or from the `MinAlm` value preset to 1 s at the beginning of the program. It remains in low power in that case, to handle the return of the line voltage to the `Mode_BACK` state:

```
case Mode_ALM:      // Wait talm seconds before
```

Listing 1: Main Blink Sequence and Mains Monitoring Routine.

```
// On power presence, signal the occurred alarms (one blink per each alarm)
 if ((POWER == 1) && (AlmCnt > 0)) {
   switch (BlkSts) {
   case 0:          // Initialize a new Blinks cycle
     n = AlmCnt;
     STSLED=1;
     curms = 0;                        // Start ms counting
     BlkSts = 1;                       // Go to "Wait to turn off the LED"
     break;
   case 1:          // Wait CNTBLINK ms to turn off the LED
     if (curms >= CNTBLINK) {
       STSLED=0;
       n--;                            // Decrement residual Blinks counter
       curms = 0;                      // Start ms counting
       if (n > 0) BlkSts = 2;          // Go to "Wait to turn on the LED"
       else       BlkSts = 3;          // Go to "Wait for next Blinks cycle"
     }
     break;
   case 2:          // Wait CNTBLINK ms to turn on the LED
     if (curms >= CNTBLINK) {
       STSLED=1;
       curms = 0;                      // Start ms counting
       BlkSts = 1;                     // Go to "Wait to turn off the LED"
     }
     break;
   case 3:          // Wait CNTINTERV for next Blinks cycle
     if (curms >= CNTINTERV) {
       curms = 0;                      // Start ms counting
       BlkSts = 0;                     // Initialize a new cycle
     }
     break;
   }
   if (BlkSts > 0) curms += TIC;        // Increment the elapsed time counter (ms)
 }

#ifdef LOWPOW
// If no external power is present, go in Low Power Mode
if (POWER == 0) {asm{sleep};} // Sleep. Awake on Timer1 interrupt.
#endif
Delay_ms(TIC);                          // Introduce a cycle delay
```

```
                // to stop the alarm
 if (POWER == 1) { // Mains is back during Alarm
   ResetAlm();     // Stop the alarm
   if (BackMode==TRUE) Signal();
                // Signal "Mains is back" if requested
   Mode = Mode_SBY; // Manage the Power Up event

} else {           // Check end of Alarm time
```

```
   if ( ((BeepMode==FALSE)&&(curs>=talm))
   ||((BeepMode==TRUE)&&(curs>=MinAlm)) ) {
     ResetAlm();     // Suspend the alarm
     Mode = Mode_BACK; // Wait for the
                       // Power Up event
   }
 }
 break;
```

In `Mode_BACK`, it waits for the mains voltage to return and signals the event by triggering the alarm for two short consecutive pulses if provided by the *Back* DIP switch. Until the grid returns, the PIC is left in low-power mode:

```
case Mode_BACK:    // Waiting for the mains power
                   // to come back again

  if (POWER == 1) {    // Mains
                  // is back: exit to Standby mode
    ResetAlm();        // Force
                       // alarm off
    if (BackMode==TRUE) Signal();
               // Signal "Mains is back" if requested
    Mode = Mode_SBY;
  }
  break;
```

After the main automaton, a second four-state automaton was implemented just to manage D5 connected to RA0.

This LED is intended to show the current count of voltage drop events of duration longer than the delay time. The `AlmCnt` counter is resettable by pressing SW1, managed in the first lines of code of the main cycle, seen above. The handling of flashes by an automaton is dictated by the need to not interrupt the main cycle with simple delays, which would block any other actions during their execution. Flashing times are defined by the constants `CNTBLINK` set to 200 ms, and `CNTINTERV`, which defines the pause between two blocks of flashes, set to 3 s (**Listing 1**).

Printed Circuit Boards

For both the analog and digital versions, two single-sided, jumperless printed circuit boards have been designed. This will undoubtedly facilitate their creation using the classic methods of photoengraving, or hot transfer. You can download the Gerber files needed for DIY from the Elektor Labs page for this article [1].

Assembly

In the analog version shown in the assembly plan, the SW1 switch for mode selection is wired to a six-way connector on the printed circuit board. You can connect a lever switch to it, or any DPDT switch. The digital version of the device, which can be seen in the mounting plan, involves socket-mounting the microcontroller, two miniature-type trimmers, a two-way dip-switch, and a jumper.

The 1.5 F supercapacitor is a special component, but nevertheless readily available. In this version, the alarm output is provided via a three-way terminal, which allows the user to choose NC or NO activation type, depending on the intended use. This is not possible in the analog version, due to circuit limitations.

The digital version thus offers greater versatility and ease of use than the analog one, thanks to the ability to configure the alarm output according to one's needs. However, the analog version retains a structural simplicity that may be advantageous in some specific applications. The choice between the two versions will therefore depend on the user's needs and the features of the signaling system to which the device will be connected.

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Questions or Comments?

Do you have technical questions or comments about this article? You may write to the author at info@purchiaroni.com or to Elektor's editorial team at editor@elektor.com.

About the Author

Passionate about electronics and programming, Stefano Purchiaroni shares his works by publishing projects, and also offers free robotics lessons for teens at a popular school. He is currently employed in Telespazio and works in a satellite center near the Italian capital.

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[1] Elektor Labs page for this article: https://elektormagazine.com/labs/mains-power-outages-monitor

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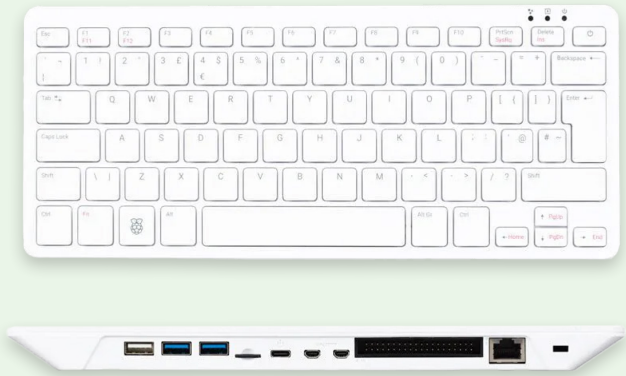

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