



159159

Electronic Regulator for Two-wire AC Switch

Description

1 Background of the Invention

5 1.1 Brief revisit of 2-Wire Switches

The use of two-wire AC switches providing electronic control of AC loads, for example, ceiling light fixtures like fluorescent tubes, energy saving lights, dimmable incandescent lamps or ceiling fans, has received considerable attention in recent times [1-7] (see References section). These electronic two-wire AC switches contain DC
10 harvesting circuitry that harvests DC power from the two wires, i.e. the active wire and the AC load wire, that are found in many common wall switch recess. It should be noted that the neutral wire is absent in these wall-switch recesses. This implies that the electronic two-wire AC switches can only access the neutral wire indirectly through the AC load.

15 Two-wire AC switches providing electronic control of AC loads use DC-powered devices to provide additional levels of switch controls. Hence, two-wire AC switches must harvest DC power to power these DC devices. For example, a DC-powered RF (radio frequency) receiver can be added in the two-wire AC switch so that the control of the AC load can be issued remotely via the use of a complementary handheld RF remote
20 controller. Alternative DC-powered sensor-based devices can also be added, for example, temperature/ radar/ infra-red/ ultrasonic/ movement/ security/ light-level/ break-contact sensors so that a switch command is issued whenever there is a change in state in any of these sensors. All these DC-powered devices have to be supplied with DC power for a protracted length of time so that they can provide these additional switch control services
25 without disruption. Figure 1 illustrates a typical 2-wire AC switch block diagram where it is noted that a small current I_{small} is used by the DC harvesting circuitry to provide a DC



G00001

positive rail to supply power to a number of DC devices. For example, a DC-powered RF receiver can be used to receive signals from a remote controller. The received signal is then communicated to another (DC-powered) AC switch control circuitry which controls the closing/breaking of the main AC supply switch S_{AC} . Of course, if the harvested DC supply is large enough, more DC-powered devices can be added to extend the functionality of the 2-wire AC switch. However, it should be noted that in order to ensure the continued operation of the 2-wire AC switch and its associated DC-powered functionalities, it is clear that its DC harvesting circuitry must continuously draw some current, I_{small} , to maintain the stability of the DC positive rail in Figure 1. The value of I_{small} depend on the DC supply rate of the DC harvesting circuitry which in turn depend on the DC consumption requirements of the DC devices used in the 2-wire AC switch.

1.2 Purpose for Electronic Regulator

Perhaps the most important factor in Figure 1, motivating the use of an electronic regulator (and which will be described soon), is the I_{small} current that needs to be continuously supplied to the 2-wire AC switch even when the AC load L_{AC} is 'off'. The AC load L_{AC} can represent a single lamp (incandescent, halogen, fluorescent, energy saving), or represent a parallel combination of AC loads. Notice that when main AC switch S_{AC} is broken (so that AC load L_{AC} is 'off'), I_{small} must still be supplied to the 2-wire AC switch. Since the neutral wire is behind the AC load L_{AC} , this means that I_{small} must also pass through L_{AC} in order to complete the current path. Therefore, the RMS voltage $V_{L_{AC}}$ across the AC load is not zero even when L_{AC} is 'off'. For convenience and in reference to Figure 1, we now define two voltage scenarios, $V_{L_{AC},off}$ and $V_{L_{AC},on}$, for AC load L_{AC} as follows:

- When L_{AC} is 'off' (characterized by main AC switch S_{AC} in the opened position), I_{small} flows through L_{AC} and hence a corresponding non-zero voltage $V_{L_{AC},off}$ will appear across L_{AC} .

- When L_{AC} is 'on' (characterized by main AC switch S_{AC} in the closed position), $I_{small} + I_{large}$ flows through L_{AC} and a large voltage $V_{L_{AC},on}$ will appear across L_{AC} . It is noted in [1-7] that when main AC switch S_{AC} is in the closed position, it is almost like a short circuit. Thus $V_{L_{AC},on}$ is of similar magnitude to the AC supply voltage V_{AC} .

5 Now, in the context of modern usage, the DC harvesting circuitry of the 2-wire AC switch require I_{small} in the range of 30 mA RMS in order to supply sufficient DC power to operate RF transceiver chips like the Chipcon CC1000 IC transceiver (which require at least 30 mA DC when transmitting). If L_{AC} is an energy saving gas-discharge lamp or a conventional glow-tube starter actuated fluorescent lamp, then what happens is that when
10 $V_{L_{AC},off}$ exceeds 60V, the lamp turns on momentarily and then shuts off again when $V_{L_{AC},off}$ drops below 60V. This irritating flashing phenomenon takes place every 50/60 Hz cycle, where the lamp is supposedly to be 'off'! One solution is to reduce I_{small} , but that would constrain the type of DC-powered chips that can be used in the 2-wire AC switch, thereby limiting its usefulness and functionality. A better solution is to connect a shunt
15 device across L_{AC} (i.e. parallel with L_{AC}) as illustrated in Figure 2 to help keep $V_{L_{AC},off}$ below 60V. For example, for $I_{small} = 30$ mA (RMS), and to keep $V_{L_{AC},off}$ below 60V, a shunt device with a 1.4 k Ω impedance can be used.

As illustrated in Figure 2, there are about 4 options to the type of shunt devices that may be used as a helper circuit to the 2-wire AC switch. For the case of $I_{small} = 30$ mA
20 (RMS) or higher, the first three options are not be appropriate for the following reasons:

- Option 1 (pure resistive shunt): To keep $V_{L_{AC},off}$ below 60V, a resistance value of at most 1.4k Ω is required. But when L_{AC} is in the 'on' state such that $V_{L_{AC},on} \approx V_{AC}$, then for a 230V AC supply system, this means the shunt resistor must be capable of dissipating 38 Watts of heat. Only wire-wound resistors about the size of a man's fist
25 fit this bill. This is clearly an impractical and expensive option to include in ceiling lamp fixtures where space is confined.

- Option 2 (pure capacitive shunt): To keep $V_{L_{AC},off}$ below 60V, a 240-volts AC capacitor value of at least $2\mu F$ is required. The physical size of this option is still manageable and can be used for connection within the confined space of ceiling light fixtures. However, the $2\mu F$ capacitive impedance is a considerable value and creates a large power factor angle in the event L_{AC} is 'on'. This creates more imaginary power component and reduces the real power efficiency of the lamp load considerably.
- Option 3 (a resistive and capacitive shunt): This circuit has been claimed in [7]. The use of which is perhaps to obtain a more balanced shunting effect compared to the case of using a purely resistive (Option 1) or a purely capacitive shunt (Option 2). This removes the extremity associated with a purely resistive or purely capacitive shunt. Although, the extremities are reduced, the resistive shunt will still dissipate power and the capacitive shunt will still increase the power factor angle.

Therefore, it is the purpose of this document to disclose, perhaps for the first time, a electronic shunting device, henceforth electronic regulator (Option 4 in Figure 2), for use as helper circuit, for any two-wire AC switch device. The said electronic regulator is particularly useful for I_{small} requirements in the large mA range since its working principle is as follows:

- When L_{AC} is 'off' (characterized by main AC switch S_{AC} in the opened position), the electronic regulator is designed to act almost like a short circuit. Consequently, $V_{L_{AC},off} \approx 0$, negligible power dissipation occurs at the AC load end so that I_{small} is used primarily for the 2-wire AC switch to farm DC power for its peripheral chips.
- When L_{AC} is 'on' (characterized by main AC switch S_{AC} in the closed position), the impedance of the electronic regulator is designed to rise instantaneously to an extremely large value. Consequently, all the AC current is channeled into the AC lamp load, which is desired.

It should be noted that a PTC-thermistor (positive temperature coefficient), if used as the shunt device in Figure 2, will have similar type of impedance change as the electronic regulator. I.e., when L_{AC} is 'off', the PTC-thermistor will have a small impedance (just a

few ohms) so that I_{small} flows through the PTC-thermistor. When L_{AC} is 'on', the PTC-thermistor will have a large impedance (in the mega ohms range) so that $I_{large} + I_{small}$ flows through the AC load L_{AC} . However, a PTC-thermistor shunt device is still inappropriate for the following reason – it works on temperature change brought about by difference in the current through the PTC-thermistor. So the time to change from low impedance to high impedance state and vice versa is in the range of several seconds. This means that the correct L_{AC} lamp state follows several seconds after there is a change in the 2-wire AC switch state. From a user's point of view, this is clearly unacceptable.

The work of the electronic regulator differs greatly from resistive/capacitive/PTC-thermistor shunt devices. The electronic regulator is based on original and novel design involving electronic discrete devices which automatically sense the change in the 2-wire AC switch state to alter its impedance value instantaneously. The impedance of the electronic regulator is altered by switching on/off an electronic switch that is connected in parallel to L_{AC} . Hence an instantaneous impedance change from just a few hundred ohms to several hundred kilo ohms and back again can be achieved instantaneously. No temperature-based devices like thermistors are used in the electronic regulator. Instead, novel switch-mode circuitry is employed so that if there is no need for the regulator to use energy, a switch is turned off, keeping heat dissipation negligible.

2 Specification

2.1 Overview of Electronic Regulator circuit

Figure 3 illustrates the schematic diagram of the said electronic regulator which is connected in parallel to AC electrical load L_{AC} and in series to an electronic 2-wire switch circuit. In reference to Figure 3, we now define the following terms:

- 'AC-off': This refers to the condition where the AC switch S_{AC} of the electronic 2-wire AC switch is off. Hence overall current flowing through the circuit of Figure 3 is I_{small} .
- 'AC-on': This refers to the condition where the AC switch S_{AC} of the electronic 2-wire AC switch is on. Hence overall current flowing through the circuit of Figure 3 is

I_{large} . More precisely, it should be $I_{small} + I_{large}$, but for sake of succinctness, we drop the I_{small} term since I_{large} already conveys the idea that there will be large current flowing when S_{AC} is closed.

- Regulator ‘on’: This refers to the electronic regulator in the ‘on’ state. Specifically, this means the shunt transistor switch Q_s (of Figure 3) of the electronic regulator is in the conducting state. It should also be noted that when the electronic regulator is in the ‘on’ state, it corresponds to the low impedance state of the electronic regulator. Hence, when ‘AC-off’, the electronic regulator must be ‘on’ so as to shunt the I_{small} current away from the AC lamp load L_{AC} , thereby preventing flashing behavior from L_{AC} .
- Regulator ‘off’: This refers to the electronic regulator in the ‘off’ state. Specifically, this means the shunt transistor switch Q_s (of Figure 3) of the electronic regulator is in the non-conducting state. It should be noted that when the electronic regulator is in the ‘off’ state, it corresponds to the high impedance state of the electronic regulator. So when ‘AC-on’, the electronic regulator must be ‘off’ so that all the I_{large} current is directed towards the AC lamp load L_{AC} to power it.

Now, the electronic regulator schematic of Figure 3 consists of several key sub-circuit components as follows:

- A bridge rectifier circuit BR , connected in parallel with the AC load L_{AC} , whose purpose is to provide full-wave rectification so that all the sub-circuits of the electronic regulator only operate under conditions of one-way current directions.
- An electronically controlled shunt-switch sub-circuit SC_{shunt} , consisting preferably of a common-emitter mode PNP transistor switch Q_s , henceforth shunt-switch, that is activated by another common-emitter mode NPN transistor switch Q_g , which is in turn controlled by an output signal V_g emanating from controller unit CU (to be described later).

- 5 • A sub-circuit SC_{SL} for detecting a transition from ‘AC-off’ (i.e. current = I_{small}) to ‘AC-on’ (i.e. current = I_{large}). The sub-circuit SC_{SL} consists preferably of a voltage divider circuit $R_4 | R_5$ where the voltage V_5 (at the dividing point) is an input signal feedback to the CU module in order for the CU to decide whether to turn off shunt-switch Q_s .
- 10 • A sub-circuit SC_{LS} for detecting a transition from ‘AC-on’ (i.e. current = I_{large}) to ‘AC-off’ (i.e. current = I_{small}). The sub-circuit SC_{LS} consists preferably of a divider circuit where the top circuit is a resistor R_{10} while the bottom circuit consist of an RC circuit $R_1 | C_1$ in parallel to a series circuit consisting of diode D_1 and another RC circuit $R_2 | C_2$. The voltages V_1 and V_2 at RC circuits $R_1 | C_1$ and $R_2 | C_2$ serves as input signal feedbacks to the CU module for CU to decide whether to turn on shunt-switch Q_s .
- 15 • A switched-mode DC harvesting sub-circuit SC_{DC} consisting of

 - a PNP charge path transistor switch Q_{DC} , henceforth DC-charge-switch, operating in common-emitter mode;
 - a NPN transistor Q_{14} , operating in common emitter mode as well, that is controlled by the CU (via output signal V_{14}) for the purpose of turning on/off DC-charge-switch Q_{DC} ;
 - a charge path resistor R_3 in series with a DC charge reservoir C_3 for the purpose of storing a stable DC energy to power the CU for a protracted period of time; and finally,
 - a voltage divider circuit consisting of R_{15} and R_{16} where the voltage V_{16} at the dividing point is an input signal feedback to the CU for the CU to decide whether to allow/disallow charging current flow via the control of Q_{14} (which in turn controls the DC-charge-switch Q_{DC}), so as to sustain a stable DC voltage line.
- 25 • A controller unit CU , for example, an 8051/PIC/AVR-based micro-controller IC, or ASIC (application-specific IC) chip, which form the heart of the system for

controlling shunt-switch Q_s and the DC-charge-switch Q_{DC} . The controller unit CU forms the core logic of the switch circuit and its behavior is configurable either through software means or hardware means. For reasons that will be provided later, the CU is to be preferably equipped with

- 5 ○ at least one voltage comparator facility where an external voltage input, i.e. V_{16} , can be compared with an internally generated voltage reference V_{ref} (see later).
- at least one voltage comparator facility where two external voltage inputs, i.e. V_1 and V_2 , can be compared against each other.

Control logic residing in CU can be divided into three main categories and listed in decreasing order of importance:

- 10 ○ *Logic to ensure stable DC harvesting* (PL_{DC}): The first priority logic PL_{DC} ensures that at all times, stable and sufficient DC voltage is maintained on the positive DC line (V_{dd}) with respect to the DC ground line (Gnd). This is achieved by monitoring for changes in V_{15} and outputting appropriate signals on V_{14} (so as
- 15 to turn on/off the DC-charge-switch Q_{DC}). This is to ensure that the CU can operate all its control logic in a stable and expected manner for a protracted length of time.
- *Logic to control shunt-switch Q_s* (PL_{SS}): The second priority logic PL_{SS} can be easily handled by CU as long as the first priority logic PL_{DC} is achieved. The
- 20 second priority logic PL_{SS} is achieved by monitoring for changes in feedback voltages V_1 , V_2 and V_5 and outputting appropriate signals on V_9 (so as to turn on/off the shunt-switch Q_s).
- *Logic to communicate and interact with Auxiliary DC Device(s)* (PL_{Aux}): Since
- 25 DC power is harvested to power the CU , this means that other DC-powered chips, for example, IR/radar/temperature detectors, movement detectors, or light level or security detectors, can also be incorporated into the electronic regulator and powered by the same DC voltage rail as the CU , so as to provide more functionality to the electronic regulator. Hence, if there is such need for an

auxiliary device (perhaps in the future), a third priority logic PL_{Aux} , made up of the remaining processing capabilities of CU , is required to communicate and interact with these auxiliary devices. The first priority logic PL_{DC} and the second priority logic PL_{SS} does not require complex logic since they only require waiting for certain voltage levels to change and then actuating either the shunt-switch Q_s or the DC-charge-switch Q_{DC} . Therefore, a significant portion of the processing capability of say, a 12 MHz CU , can be used to communicate, interact and control a multitude of auxiliary DC devices.

Several more issues in regard to the electronic regulator of Figure 3 are still unclear. For example, at initial start-up, charge reservoir C_3 is empty and thus is incapable of powering up CU . Since CU is not powered up, it is incapable of actuating control signal V_{14} to turn on Q_{14} , which in turn turns on Q_{DC} , to replenish the reservoir capacitor C_3 . The next section provides more details of the switched-mode DC harvesting sub-circuit and explains several other important characteristic of the CU IC that allows for a smooth start-up and smooth operation of the current invention. Thereafter, details of priority logics PL_{DC} and PL_{SS} are provided to complete the picture.

2.2 Detailed Circuit Specification

All descriptions in this section again refer to Figure 3. For ease of explanation, the following notations are introduced as follows:

$V_{CU,min}$: The minimum operating voltage of CU , as recommended by its manufacturer, to ensure a stable, consistent and predictable operation for an unlimited period of time.

$V_{CU,max}$: The maximum operating voltage of CU , as recommended by its manufacturer, to ensure a stable, consistent and predictable operation for an unlimited period of time.

$V_{CU,Op}$: The optimal operating voltage of CU , as recommended by its manufacturer, to ensure a stable, consistent and predictable operation for an unlimited period of

time. Usually, $V_{CU,Op} = \frac{V_{CU,min} + V_{CU,max}}{2}$ and $V_{dd} = V_{CU,Op}$ so that if there is any slight variation in the DC supply source V_{dd} , the operation of CU is not affected.

V_{ref} : The internal reference voltage V_{ref} used in the voltage comparator function of CU .

Usually $V_{ref} < V_{CU,Op}$ and is internally generated within CU as long as

5 $V_{CU,min} \leq V_{dd} \leq V_{CU,max}$. V_{ref} is also an *absolute* voltage reference and its value is independent of V_{dd} .

The detailed explanations in regard to Figure 3 are now provided in the following sections.

2.2.1 Switched-Mode DC harvesting sub-circuit

10 The SC_{DC} block in Figure 3 illustrates the preferred embodiment of the switched-mode DC harvesting sub-circuit consisting of electronic solid-state switching elements in the form of PNP transistor Q_{DC} and NPN transistor Q_{14} . Supporting these transistors are resistors R_{11} , R_{12} , R_{13} and R_{14} . For energy storage and desired DC voltage maintenance, a charge path resistor R_3 , a charge reservoir C_3 and a voltage sensing divider circuit
15 consisting of R_{15} and R_{16} are also part of the switched-mode DC harvesting sub-circuit. There are several important features of the switched-mode DC harvesting sub-circuit and they are now explained as follows:

- In regard to transistors Q_{DC} and Q_{14} , they are common-emitter transistor switches (since their controlled circuit is on their collector side).
- 20 • It should be noted that when Q_{14} conducts (i.e. 'on'), Q_{DC} conducts charging current to the charge capacitor C_3 . Conversely, when Q_{14} is 'off', Q_{DC} is also 'off'. Hence the states of Q_{14} and Q_{DC} are *exactly in tandem*.
- Another important factor is the initial start-up process associated with CU . As mentioned earlier, at initial start-up, charge reservoir C_3 is empty and thus is incapable
25 of powering up CU . Since CU is not powered up, it is incapable of actuating its output pin V_{14} to replenish the reservoir capacitor C_3 . Now, to overcome the initial start-up dilemma, an important point should be noted in regard to CU :

- The V_{14} pin of CU is *always* a **high impedance** pin as long as $V_{dd} < V_{CU,min}$. There is currently a large number of commercially available CU devices that exhibit this property, i.e., before the supply voltage reaches the minimum operating voltage (i.e. $V_{CU,min}$) of CU , all of its general purpose IO (input/output) pins are by default, high impedance pins. Once the supply voltage exceeds $V_{CU,min}$, the CU starts operating and the default high impedance pins can be configured by its start-up logic to operate as normal low impedance bi-directional I/O pins.

With the aforesaid property, it is thus noted that at start-up, since $V_{dd} = 0$, V_{14} is a high impedance path (since CU is not in operation). Therefore current flow into R_{13} will avoid the V_{14} path and instead flow into R_{14} and into the base of Q_{14} . This causes Q_{14} to conduct, drawing current out of the base of PNP transistor Q_{DC} . Subsequently, Q_{DC} conducts causing the charge reservoir C_3 to charge up. Once the charge-up voltage in C_3 exceeds $V_{CU,min}$, CU starts operating and the control logic in CU now takes over the control of the very important DC-charge actuating signal V_{14} . In many commercially available CU devices, it is common to find a large operating voltage range for which CU operates stably. For example, between $V_{CU,min} = 2.4$ volts and $V_{CU,max} = 3.6$ volts is common for a $V_{CU,Op} = 3$ volts CU device. Since the charge rate of C_3 is proportional to the 50/60 Hz AC supply source, therefore, when the charge voltage in C_3 reaches $V_{CU,min}$, there is more than sufficient time, say for a 12 MHz CU , to initialize and execute its control logic to control V_{14} before the charge voltage in C_3 exceeds $V_{CU,max}$.

- When CU is in operation, it needs to take control of V_{14} to actuate/de-actuate the DC-charge-switch Q_{DC} so as to control charging current flow, thereby stabilizing the DC voltage. To control V_{14} , a voltage divider circuit consisting of R_{15} and R_{16} is used to produce a voltage level V_{16} that is some fraction of V_{DD} . Input signal V_{16} is connected to one of CU 's voltage comparator input pins. The main reason for using a fraction of V_{dd} as the feedback signal is essentially due to the internal reference voltage V_{ref} used in the voltage comparator function of CU . In the majority of devices capable of CU

functionalities, the internal reference voltage V_{ref} used for analog comparator functions is a fraction of the optimal voltage $V_{CU,Op}$ required to energize CU , i.e. $0 < V_{ref} < V_{CU,Op}$. The optimal voltage $V_{CU,Op}$ is defined to be the optimal supply voltage recommended by the manufacturer of CU to ensure the optimal operation of CU for an unlimited period of time. There is also some possibility that CUs with ADC (analog to digital converting) inputs can also be used. However, it should be noted that the majority of ADC comparisons are relative to the *instantaneous* V_{dd} voltage supplied to the CU . Without an absolute voltage reference, ADC comparisons may not be suitable for the current art since V_{dd} , on its own, is not stable. However, if ADC inputs are to be used, then it is imperative that the ADC comparisons are absolute voltage comparisons and independent of the current V_{dd} level. Returning to the voltage divider circuit in Figure 3, it is noted that the values of R_{15} and R_{16} is chosen such that $\frac{R_{15}}{R_{16}} = \frac{V_{ref}}{V_{CU,Op}}$. In addition, R_{15} and R_{16} should have large resistor values so that power dissipation through the voltage divider circuit is negligible. Hence, when V_{16} drops below V_{ref} , it signals to CU that V_{DD} is below $V_{CU,Op}$. Conversely, when V_{16} rises above V_{ref} , it signals to CU that V_{DD} is above $V_{CU,Op}$. Now, associated with keeping the DC line voltage V_{dd} stable and close to $V_{CU,Op}$, two needful operations are performed by CU and they are now described as follows

- **Stop-charge operation:** When it is sensed that V_{16} has exceeded V_{ref} , CU outputs a 'low' (i.e. 0 volts) on V_{14} , thereby causing current to be drawn away from the base of Q_{14} , shutting off Q_{14} . This also removes base current from transistor Q_{DC} causing Q_{DC} to stop conducting. The voltage in the charge reservoir C_3 now depletes as CU and possibly, other auxiliary DC devices, are still drawing DC supply. Another possible stop-charge operation can be described as follows: When it is sensed that V_{16} has exceeded V_{ref} , rather than shutting off Q_{14} and Q_{DC} immediately, CU delay for some time first. This can be achieved using count-down timers as these are standard features in many commercially available CU devices.

With the additional delay, V_{dd} will continue to increase its voltage beyond $V_{CU,op}$. Noting that the charge rate of C_3 is related to the 50/60 Hz AC supply rate, it is rather straightforward to design a delay value that expires before V_{dd} exceeds $V_{CU,max}$ (since that would render the CU inoperable). On expiry of the delay, CU proceeds to output a 'low' (i.e. 0 volts) on V_{14} , thereby shutting off Q_{14} and Q_{DC} . The second stop-charge operation provides for more energy storage into the charge reservoir. Consequently, CU can operate longer without requiring a fresh charge.

- **Begin-charge operation:** CU performs the begin-charge operation as long as the following two conditions are satisfied: (1) CU is currently in the stop-charge state (i.e. both Q_{14} and Q_{DC} are not conducting) and (2) V_{16} has dropped below V_{ref} . Accordingly, CU proceeds to output a 'high' on pin V_{14} which turns on Q_{14} and subsequently, Q_{DC} . Charging current flows into C_3 via Q_{DC} and R_3 . When the charge reservoir C_3 is replenished (i.e. V_{16} is now higher than V_{ref}), the stop-charge process (as described earlier) is initiated once again.

15 2.2.2 Sub-circuit SC_{shunt} for actuating shunt-switch Q_s

In Figure 3, the sub-circuit SC_{shunt} consisting of R_6 , R_7 , R_8 , R_9 , Q_8 and output pin V_9 from CU form the means for actuating the shunt-switch Q_s . There are several important features of the SC_{shunt} sub-circuit and they are now explained as follows:

- In regard to transistors Q_s and Q_8 , they are common-emitter transistor switches (since their controlled circuit is on their collector side).
- It should be noted that when Q_8 conducts (i.e. 'on'), Q_s shunts current away from the AC load L_{AC} . Conversely, when Q_8 is 'off', Q_s is also 'off' so that AC current is directed towards L_{AC} . Hence the states of Q_8 and Q_s are *exactly in tandem*.
- Irrespective of the Q_s state, some small amount of current will always be directed towards the switched-mode DC harvesting sub-circuit when SC_{DC} closes the DC-charge-switch Q_{DC} . As mentioned earlier, keeping the DC power supply stable and constant is always the first priority of the electronic regulator. This current drawn, if it

is just for the DC power needs of a modern day CU , is negligible (less than 1 mA) and should not affect much the operation of the L_{AC} load.

Now, the opening/closing of Q_S is controlled by the CU 's output pin V_9 . To open Q_S , CU outputs a 'low' (i.e. 0 volts) on V_9 , thereby causing current to be drawn away from the base of Q_8 , shutting off Q_8 . This also removes base current from transistor Q_S causing Q_S to stop conducting. To close Q_S , CU output a 'high' on pin V_9 which turns on Q_8 and subsequently, Q_S .

Circumstances leading to the opening/closing of Q_S depend on input voltage V_5 arising from sub-circuit SC_{SL} and input voltage pair V_1 and V_2 arising from sub-circuit SC_{LS} . The following sub-sections provide specific details on sub-circuits SC_{SL} and SC_{LS} .

2.2.3 Sub-circuit SC_{SL} for detecting 'AC-off' (i.e. current = I_{small}) to 'AC-on' (i.e. current = I_{large})

As mentioned earlier, the sub-circuit SC_{SL} in Figure 3, consisting of voltage dividing resistors R_4 | R_5 connected in series to the collector pin of shunt-switch Q_S , provide the means for detecting a transition from 'AC-off' (i.e. current = I_{small}) to 'AC-on' (i.e. current = I_{large}). The voltage V_5 at the voltage dividing point is the feedback signal to CU . When current I_{small} is flowing, the shunt-switch Q_S is in the closed state (i.e. CU is currently outputting a 'high' voltage on pin V_9). Hence the voltage at V_5 is a small voltage when I_{small} is flowing. The values of R_4 and R_5 should therefore be chosen so that when I_{small} is flowing, the V_5 input to the CU registers a logic 'low' signal to the CU . When the main AC switch S_{AC} in the 2-wire AC switch is suddenly turned on, a large current I_{large} will suddenly flow through Q_S . The voltage V_5 rises quickly, crossing the CU 's logic high threshold, indicating immediately to CU that a transition from 'AC-off' (i.e. current = I_{small}) to 'AC-on' (i.e. current = I_{large}) has just occurred. Accordingly, CU turns off the shunt-switch Q_S . It is noted that turning off the shunt-switch Q_S also

disables current from flowing through SC_{SL} so that the SC_{SL} sub-circuit has no functional purpose. Hence it is important to note that the SC_{SL} circuit is only used for detection purposes when Q_s is 'on'. Other than this scenario, the CU control logic should ignore V_s . Once Q_s is 'off', the CU 's focus is now on sub-circuit SC_{LS} (to be explained in the next section) to provide a signal for CU to turn Q_s back 'on' again. Finally, another design consideration for R_4 and R_5 is that their total resistor values should be smaller than the L_{AC} impedance so that the SC_{SL} sub-circuit forms an effective shunt path (i.e. when Q_s is 'on' and I_{small} is flowing).

2.2.4 Sub-circuit SC_{LS} for detecting 'AC-on' (i.e. current = I_{large}) to 'AC-off' (i.e. current = I_{small})

As mentioned earlier, the sub-circuit SC_{LS} in Figure 3, consisting of a divider circuit where the top circuit is a resistor R_{10} while the bottom circuit consist of an RC circuit $R_1|C_1$ in parallel to a series circuit consisting of diode D_1 and another RC circuit $R_2|C_2$, provide the means for detecting a transition from 'AC-on' (i.e. current = I_{large}) to 'AC-off' (i.e. current = I_{small}). The voltages V_1 and V_2 at RC circuits $R_1|C_1$ and $R_2|C_2$ serves as input signal feedbacks to the CU module for CU to decide whether to turn on shunt-switch Q_s . It should be noted that the SC_{LS} sub-circuit is only used for detecting a transition from 'AC-on' to 'AC-off'. Hence it has functional purpose only when Q_s is 'off'. When Q_s is 'on', the CU 's control logic should therefore ignore input feedback signals V_1 and V_2 . It should also be noted that the RC circuits $R_1|C_1$ and $R_2|C_2$ should be designed such that in the event the current reduces from I_{large} to I_{small} , the $R_1|C_1$ circuit discharges voltage faster than the $R_2|C_2$ circuit does. This can be easily designed by choosing components so that the RC time constant of $R_1|C_1$ is smaller than the RC time constant of $R_2|C_2$. In addition, the purpose of SC_{LS} sub-circuit is only for voltage sensing purposes and not for shunting current, hence the impedance in the SC_{LS} sub-

circuit should be designed to be much larger than the AC load L_{AC} . Now, when I_{large} is flowing (mainly through AC load L_{AC} since Q_S is 'off' and SC_{LS} is high impedance), the voltage V_1 will be higher than V_2 by virtue of diode D_1 . So when there is a transition from I_{large} to I_{small} , because of the smaller RC time constant of $R_1|C_1$, the V_1 feedback signal will drop faster than the V_2 feedback signal. As mentioned earlier, the V_1 and V_2 feedback signals are external inputs to the CU 's voltage comparator facility. Therefore, once it is detected (by the CU 's comparator) that V_1 has dropped below V_2 , it signals to CU that a transition from I_{large} to I_{small} has taken place. Accordingly, the CU turns the shunt-switch Q_S 'on' and shifts the voltage monitoring process to V_5 .

2.3 Details of Priority Logics PL_{DC} and PL_{SS}

The two bread and butter priority logics of the electronic regulator is now explained in detail. The first priority logic PL_{DC} takes precedence over the second priority logic PL_{SS} .

Now, the first priority logic PL_{DC} is rather straightforward. In reference to Figure 3, the work of PL_{DC} is to monitor DC feedback voltage V_{16} constantly so that if it exceeds the internal reference voltage V_{ref} of the CU , the CU outputs a 'low' signal on V_{14} to turn off the DC-charge-switch Q_{DC} . Conversely, if DC feedback voltage V_{16} falls below the internal reference voltage V_{ref} , the CU outputs a 'high' signal on V_{14} to turn on the DC-charge-switch Q_{DC} .

In reference to Figure 3, the second priority logic PL_{SS} monitors a sudden rise in feedback signal V_5 , only when Q_S is 'on'. When there is a sudden rise in feedback signal V_5 when Q_S is 'on', CU outputs a 'low' signal on V_9 to turn off the shunt-switch Q_S . When Q_S is 'off', PL_{SS} now monitors for the condition that feedback signal V_1 falls below V_2 . If V_1 falls below V_2 , CU outputs a 'high' signal on V_9 to turn on shunt-switch

Q_s . When Q_s is turned 'on', PL_{SS} goes back to monitoring feedback signal V_s for a sudden rise, and the process repeats.

2.4 Additional Protection Circuitry

Additional protection circuitry can also be added to the preferred embodiment (i.e. Figure 3) of the current invention. Figure 4 illustrates these protection circuits when included in the circuit diagram of Figure 3. In Figure 4, a fuse F is added on the Active wire supply which limits the maximum AC current through the electronic regulator. Also included in Figure 4 is a bi-directional TVS (Transient Voltage Suppressor) diode D_{TVS} connected in parallel to the bridge rectifier BR . The use of D_{TVS} is to suppress unwanted voltage spikes which may affect the operation of the electronic regulator. To prevent the possibility of accidental (and unexplainable) overcharging situations in the DC harvesting process, a Zener diode D_{Zener} can also be connected in parallel with the SC_{DC} as illustrated in Figure 4. The Zener breakdown voltage rating in D_{Zener} should be chosen high enough such that D_{Zener} does not break down when V_{dd} is at its desired level. Diode D_{Zener} should only breakdown, thus protecting CU , only in the event V_{dd} rises above the maximum operating voltage of CU .

It should be noted that the protection circuitry illustrations in Figure 4 are not intended to be restrictive. It should be clear to experts in the current art that a plethora of other protection circuitry variations can just as well be added with little evidence of an inventive step taken.

2.5 Other Circuit Realizations

While Figures 3 and 4 illustrates the various preferred embodiments of the current invention, it should be noted that equivalent functionalities of the current invention can just as well be realized by a plethora of different circuitry, or different components with different parametric values. These variations in circuitry only exhibit trivial variations and do not clearly carry evidence of an inventive step that is different from all the novel features of the current invention. The circuit embodiments, described herein, are presented to demonstrate clearly the novelty of the electronic regulator and it is not

intended to be restrictive. Examples of some of these trivial variations are now presented. For example, Figure 5 illustrates a DC-charge-switch variation of Figure 3 where the main current carrying switch is an NPN transistor Q_{DC} which is triggered by a PNP transistor Q_{14} . Both Q_{DC} and Q_{14} transistor switches are all operating in the common-emitter switch mode be it in Figure 3, Figure 4 or in Figure 5. It is clear that Figures 3, 4 and 5 are equivalent and only demonstrates a preference with no particular inventive step. Another trivial variation, as illustrated in Figure 6, involve replacing Q_{DC} and Q_{14} in the switched-mode DC harvesting sub-circuit SC_{DC} with a single break contact electronic IC switch S_{DC} (i.e. when there is no power, the said electronic IC switch conducts). Similarly, in Figure 6, transistors Q_s and Q_8 in the shunt-switch sub-circuit SC_{shunt} can also be trivially replaced with an open contact electronic IC switch S_{shunt} . Another possible variation is to replace transistors Q_s , Q_8 , Q_{DC} and Q_{14} (of Figures 3, 4 and 5) with equivalent MOSFET devices.

In summary, it is important to note that a useful electronic regulator, for shunt control to an AC lamp load so as to prevent the AC lamp load from undesirable flashing behavior, when an electronic 2-wire AC switch is connected in series to the AC lamp load, is disclosed. The electronic regulator is also demonstrated to be able to provide switch-mode DC power supply to power other IC chips concurrently, thereby enabling more options for shunt control, and opening other possibilities for use in a wide application field. In addition, it is also disclosed that there is high possibility for a large number of trivial circuit variations which can be used to replace or add to the electronic regulator's preferred form, but with little evidence of an inventive step or improvement.

3 References

- [1] Alfred Vogt and Paul Greb, "Control Circuits for Thyristors", *UK Patent GB 2008870 A*, filed by Preh GmbH Walter on 16 Nov 1978, published 6 Jun 1979.
- [2] John Scholes and Donald Terrace, "Two Wire Switch Control Circuit", *Australian Patent Application AU 198930798 A1 (Patent 608416)*, filed by Gerard Industries Pty. Ltd. (Clipsal) on 28 Feb 1989, published 28 Mar 1991.

- [3] Yat Chong Koh, "Apparatus for Controlling AC Supply Switches", *UK Patent GB 2319123 A (PCT/SG97/00058)*, filed by Koh Yat Chong on 7 Nov 1996, published 13 May 1998.
- 5 [4] Peter Birrell, "Controlled Switching Circuit", *Australian Patent Application AU 199922429 A1 (PCT/AU01/01451)*, filed by H.P.M. Industries Pty. Ltd. on 26 Mar 1999, published 16 April 1998.
- [5] Kevin Chung Ping Lo, "A Two-wire Power with Line-Powered Switch Controlling Means", *Hong Kong Special Administrative Region Patent 1049265 (Singapore Patent 106097)*, filed by Easy Charm Limited on 27 Feb 2002, published 11 April
10 2003.
- [6] Xiaosong Tang, "Two-wire AC Switch using Switch-mode technology", *Singapore Patent Application D2004/2204/B*, filed by Anjels Integration (S) Pte Ltd on 17 Dec 2004.
- [7] You Quan Mi, "Three Circuits for Two-wire Multiple Load Wall Switch", *PRC*
15 *Patent 03154132.1*, filed by You Quan Mi on 11 Aug 2003, published 31 Mar 2004.

Claims

1. An electronic shunting device, henceforth referred to as an electronic regulator, connected in parallel to an AC load comprising:
5 means for detecting a transition from low current flow state to high current flow state in the AC circuit; means for detecting a transition from high current flow state to low current flow state in the AC circuit; means for actuating an electronic switch, henceforth referred to as shunt-switch Q_s , to a closed or opened position when the said detection means has detected a transition from high current flow to low current flow or has detected a transition from low current flow to high current flow respectively; the said means for actuating the said
10 shunt-switch Q_s comprising of a software/hardware programmable DC-powered controller unit, henceforth referred to as CU , with input/output facilities for sensing external input signals so as to translate them to appropriate external output signals to actuate the said shunt-switch Q_s appropriately; a switched-mode DC harvesting sub-circuit which is also controlled by the said CU via the utilization of a small portion of
15 overall AC supply, so that sufficient DC power is harvested to not only power the said CU to enable its continued operation of the said shunt-switch Q_s but also to power optional DC auxiliary devices.
2. An electronic regulator circuit, as claimed in claim 1, wherein the circuit further comprises a full-wave rectifying circuit connected in parallel to the said AC load.
- 20 3. An electronic regulator as claimed in claims 1 to 2, wherein a voltage divider circuit comprising of two resistors, connected in series to the said shunt-switch Q_s , whose voltage dividing point, henceforth referred to as V_s , is used as the said means for detecting a transition from low current flow state to high current state flow in the AC circuit, only when the said shunt-switch Q_s is in the conducting state. The said
25 voltage dividing point V_s is connected to an input pin of the said CU where a sudden rise in V_s indicates to the CU that a transition from low current flow state to high current state flow has occurred.

4. An electronic regulator as claimed in claims 1 to 3, wherein a voltage divider circuit connected in parallel to the said AC load, comprising of a resistor in series with a circuit comprising of a first RC circuit in parallel to a series circuit comprising of a diode in series with a second RC circuit, whose voltage value at the first RC circuit, henceforth referred to as V_1 , and whose voltage value at the second RC circuit, henceforth referred to as V_2 , is used as the said means for detecting a transition from high current flow state to low current state flow in the AC circuit, only when the said shunt-switch Q_s (claimed in 1) is in the non-conducting state. The said voltages V_1 and V_2 are connected to two input comparator pins of the said CU whereby when V_1 falls below V_2 indicates to the CU that a transition from high current flow state to low current state flow has occurred.
5. An electronic regulator as claimed in claims 1 to 4, wherein the electronic regulator further comprises a shunt-switch sub-circuit containing the said shunt-switch Q_s (claimed in 1). The said shunt-switch sub-circuit comprises: a common-emitter mode PNP transistor (or NPN transistor), representing the shunt-switch Q_s , which is actuated by a common-emitter mode NPN transistor (or PNP transistor) which is in turn controlled by the said CU ; or a single make contact electronic switch IC representing the shunt-switch Q_s , directly controlled by the CU ; or an electronic switch representing the shunt-switch Q_s which rely substantially on at least one FET device to achieve basic on/off switching capabilities.
6. A switched-mode DC harvesting sub-circuit as claimed in claim 1 wherein the circuit is connected in parallel to the said AC load.
7. A switched-mode DC harvesting sub-circuit as claimed in claims 1 and 6, wherein the circuit not only supplies adequate DC power to the said DC-powered controller unit, but also supplies adequate DC power to power optional DC-powered auxiliary devices.
8. A switched-mode DC harvesting sub-circuit as claimed in claims 1, 6 and 7, wherein the circuit comprises: a DC charge reservoir comprising at least one electrolytic

- capacitor, a DC-charge-switch for electronically switching on and switching off a charging current, and connection means to the said DC-powered *CU* to enable the said DC-powered *CU* to monitor a DC feedback signal, which is obtained at the voltage dividing point of a voltage divider circuit connected across the DC voltage supply line and the DC ground line, in order to control the said switched-mode DC harvesting process.
- 5
9. A DC-charge-switch as claimed in 8, wherein the switch comprises two common-emitter transistor switches, or a break contact electronic switch IC, or an electronic switch with substantial reliance on at least one FET device to achieve switching capabilities.
- 10
10. A first priority control logic governing the behavior of the said DC-powered *CU* (claimed in 1) for controlling the switched-mode DC harvesting circuitry (as claimed in 1, 6 to 8), wherein the logic monitors the voltage level of the said DC feedback signal (as claimed in 8). If the said DC feedback signal is low, then the action of the first priority control logic is to actuate the said DC-charge-switch (claimed in 8) to conduct. Conversely, if the said DC feedback signal is high, then the action of the said first priority control logic is to de-actuate the said DC-charge-switch to stop conducting.
- 15
11. A second priority control logic governing the behavior of the *CU* (claimed in 1) for controlling the shunt-switch Q_s (claimed in 1). If the said shunt-switch Q_s is conducting, then the said second priority control logic monitors for the event the said signal V_s (claimed in 3) is found to have increased in value suddenly before initiating actions to de-actuate the said shunt-switch Q_s to stop conducting. Conversely, if the said shunt-switch Q_s is not conducting, then the said second priority control logic monitors for the event the said signal V_1 (claimed in 4) drops below the said signal V_2 (claimed in 4) before initiating actions to actuate the said shunt-switch Q_s to resume conducting.
- 20
- 25
12. An electronic regulator as claimed in claims 1 to 5, wherein the circuit further comprises a bi-directional transient voltage suppression diode (and the like)

connected in parallel to the full bridge rectifier circuit as claimed in 2, for the purpose of mitigating unexpected voltage spikes.

13. An electronic regulator as claimed in claims 1 to 5 and 12, wherein the circuit further comprises a zener diode (and the like) operating just below its breakdown voltage, connected to the said DC voltage supply line (mentioned in claim 8) and the said DC ground line (mentioned in claim 8) so as to mitigate unexpected overcharge scenarios.
14. An electronic shunt circuit substantially illustrated in all the accompanying drawings and substantially described via reference to the said accompanying drawings.