



\*159159\*



\*G00002\*

# Description

## 1 Background of the Invention

The majority of wiring circuits located above ceilings of buildings are twin-core (i.e. active and neutral) wirings. In addition, twin core wiring is often used for connecting wall switches to the above ceiling active conductor and to the active side of say, a ceiling light fixture. Hence, typically, a neutral conductor is usually not available in wall switches below ceiling level and consequently, it is not straightforward the harvesting of DC power in wall switch outlets where there is no neutral conductor. It should be noted that wall switch outlets are significantly different from power outlets where three core wiring brings active, neutral and earth conductors to the power outlet point. The presence of both active and neutral conductors in power outlets make DC harvesting of power from these outlets a trivial procedure that has been reported many times over in the literature. In contrary, the two wire wall outlet scenario, where the neutral wire is absent, require switches to access the neutral conductor from behind the AC electrical load. Therefore DC harvesting in such scenarios have to consider the loading situation as well, thus making the whole DC harvesting process non-trivial. For example, the voltage across the AC electrical load (and therefore across the DC harvesting circuitry as well) is different when the AC electrical load is 'On' and when the AC electrical load is 'Off'. In addition, some AC electrical loads are resistive (incandescent lamps) with dimmable states, while others are inductive (fluorescent lamps, ceiling fan) and others, capacitive (energy saving lamps). Therefore, with the plethora of possible AC electrical loads that can be fitted to the ceiling, coupled with the possibility that various AC electrical loads are connected in parallel and controlled by one wall switch, it is indeed non-trivial for any DC harvesting circuitry to provide DC power consistently, stably and for a protracted length of time.

The harvesting of DC power from two-wire AC wall switch outlets is particularly useful (and necessary) in residential/office automation systems where the wall switch, besides allowing conventional manual (or localized) switching controls, also provide remote switching controls so that the user is able to actuate the various states of a light

fixture (viz. On, Off, Dim) via a remote controller unit located some distance away from the switch. Irrespective of the mode of wireless communication (RF (radio frequency), IR (infra-red) or Ultrasonic), DC power must be generated at the wall switch to provide power for the wireless transceiver at the wall switch to be able to communicate with the wireless transceiver at the remote controller. Further varieties of switching controls may also be supported by including additional movement/light-level/break-contact/security/radar/temperature sensors where it is clear that all of these sensor devices also require DC power. An obvious solution to this is to use battery cells to provide the DC power at the wall switch. While this is possible, it is nonetheless more cost effective to harvest the DC power from the AC current that flows through the wall switch to power these devices. In recent times as well, DC generated current may be required to be as high as 30+ mA to support the transmission function of some auxiliary RF IC (integrated circuit) chips (e.g. Chipcon CC1000 RF chip).

Two-wire switch circuits with DC harvesting capabilities have been in existence for more than 20 years [1] (see References section). For example in UK patent [1], a two-wire switch circuit was disclosed using a triac as the AC supply switch and a DC harvesting circuit consisting of a half wave rectifier, a charge reservoir and a voltage regulating circuit to ensure that the voltage of the charge reservoir does not exceed the desired DC limit. Two DC powered IC chips were incorporated into the system and powered by its DC harvesting circuitry. One of the IC is a receiver whose purpose is to receive and interpret three types of ultrasonic signals (Dim Up, Dim Down, On/Off) from a remote controller. The other IC is used to generate pulses which actuate the triac to obtain a desired on/off/dimming level. In Australian patent [2], a different 2-wire circuit was disclosed where a triac is also used as the AC supply switch but with a markedly different DC harvesting circuitry consisting of a full wave bridge rectifier, a DC charge reservoir and associated DC voltage regulating circuits. In UK patent [3], the use of opto-couplers was introduced to improve the isolation and stability features of another two-wire switch circuit. In Australian patent [4], the two-wire switch disclosed incorporated a MOSFET device as the AC supply switch. This is a significant departure from earlier two-wire switch circuits which uses the triac for controlling AC supply. Since the MOSFET can only conduct current in one direction, an electro-mechanical relay (which

can conduct bi-directionally) is also incorporated into the circuit. The MOSFET/relay circuit [4] can result in lower heat dissipation compared to triac-based circuits. However, the disadvantage of the use of a relay is contact wear, noise (when the relay switches) and the magnetic field emanating from the relay coil (which may cause some interference). A recent Hong Kong SAR (Special Administrative Region) Patent [5] for a two-wire switch with DC harvesting capabilities also uses an electro-mechanical relay but does not use any MOSFET nor triac device to control the AC power supply. Four electronic switches cleverly arranged enable the control of the relay for supplying AC power to the AC load. However, the circuit in [5] utilizes two bridge rectifier circuits and a current transformer to harvest DC power. When the load is off (high impedance state), the first bridge rectifier operates to harvest DC power. When the load is 'on' (low impedance state), the current transformer and the second bridge rectifier are used to harvest DC power. One of the stated limitations for the circuit in [5] is due to the current transformer (for harvesting DC power when the load is 'on'). Since the current transformer is connected in series with the load, the amount of DC current that can be harvested using the current transformer depends on the AC load. Harvested DC current in the range around 20 mA is possible [as stated in 5] but higher values may not be suitable. This may be inadequate for powering RF transceivers like the Chipcon CC1000 IC transceiver (which require 30 mA or larger when transmitting). Another disadvantage of a pure relay switching circuit like [5] (i.e. without MOSFET or triac) is that since the relay actuates relatively slowly (in the order of tens of a millisecond) compared to an electronic switch like a triac (which switches in the order of a few microseconds), it is highly improbable for such two-wire switch circuits to provide dimming capabilities.

## 2 Specification

### 2.1 Block Diagram Specification

The current invention discloses a new two-wire switch circuit with DC harvesting capabilities providing DC current to as high as 40 mA, which is more than sufficient to power RF transceivers like the Chipcon CC1000 as well as its own control circuitry. The current invention utilizes a triac for controlling AC supply to the AC load. The use of a

triac also allow for dimming functionalities. The current invention is also scalable whereby a multitude of AC loads can be controlled using the same base architecture with minimal component additions. Perhaps the more notable differentiating factor in the current invention from previous art [1-5] is that the current invention makes use of highly efficient switch-mode technology to achieve the DC harvesting process. It should be noted that switch-mode technology is another method of stabilizing the DC energy stored in the charge reservoir. Instead of conventional DC voltage regulation circuits, usually by way of a resistor in series with a Zener diode, switch-mode techniques break the current charging path, allowing the charge reservoir voltage to deplete before setting up the charging current path again. While switch-mode methods are commonly employed in switch-mode AC-DC transformers (where both active and neutral conductors are available), they are not commonly employed in the two-wire switch scenario where the neutral conductor can only be accessed indirectly through an AC load whose voltage is variable. None of the previous art listed in [1-5] has claimed that their associated DC harvesting methodology is switch-mode. Experts in this art should also be familiar that switch mode DC harvesting circuits are capable of producing higher current but are also cooler (less heat dissipated) than voltage regulated DC harvesting circuits.

Figure 1 illustrates the block diagram ( $S_B$ ) of the current invention consisting of a two-wire switch circuit for controlling single phase AC (Alternating Current) supply, via active conductor  $W_A$ , to an AC electrical load  $L_{AC}$  (e.g. a lamp load) where the neutral conductor  $W_N$ , is only indirectly accessible to  $S_B$  via AC load  $L_{AC}$ . The  $S_B$  block diagram consists of several key components as follows:

- An electronically controlled AC switching device in the preferable form of a power triac  $T$  which is connected in series to the AC load  $L_{AC}$ .
- A bridge rectifier circuit  $BR$ , connected in parallel with power triac  $T$ , whose purpose is to provide full-wave rectification to a DC (Direct Current) harvesting circuitry.
- A controllable electronic switch  $S_E$ , which enables/disables charging current flow through the charge path resistor  $R_1$ , so as to charge/discharge the charge reservoir capacitor  $C_1$ . The electronic switch  $S_E$ , or more specifically, the DC-charge-switch  $S_E$ , form the basis of the switch-mode DC harvesting technology. It should be noted that

conventional voltage regulating circuits involving breakdown zener diode components are absent in the current invention.

- 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 the AC supply switch  $T$  and the DC-charge-switch  $S_E$ . The controller unit  $CU$  forms the core logic of the switch circuit and its behavior is configurable either through software means or hardware means. In addition,  $CU$  is to be preferably equipped with at least one voltage comparator input with a voltage reference (more details provided later). Control logic residing in  $CU$  can be divided into four main categories and listed in decreasing order of importance:

- *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 Rail ( $V_{dd}$ ) with respect to the DC ground rail ( $Gnd$ ). The maintenance of  $V_{dd}$  must be sufficient to not only provide for  $CU$ 's own DC needs but also to a multitude of DC powered devices which can also be connected between  $V_{dd}$  and  $Gnd$ . For example, in Figure 1, a RF (radio frequency) TX/RX (Transmitter/Receiver) device  $L_{DC}$  is also connected to  $V_{dd}$  and  $Gnd$  to provide the transmitting and receiving interface for a remote controller unit operated at a remote location some distance away from  $S_B$ . To achieve  $PL_{DC}$ , two input voltage detect signals, namely input DC detect signal  $D_{DC}$  and an AC supply zero crossing detect signal  $D_{ZC}$ , is fed into two inputs of  $CU$  to provide the necessary voltage information for  $CU$  to perform coordinated control of  $T$  and  $S_E$  via two of  $CU$ 's output control signals  $O_T$  and  $O_{DC}$ . It is noted that coordinated control of both  $T$  and  $S_E$  is required because when DC-charge-switch  $S_E$  is closed (to enable the charging of capacitor  $C_1$ ), the triac  $T$  must be opened (high impedance) so that charging current can flow into the charge reservoir  $C_1$  (rather than to  $L_{AC}$ ). Since the charging of  $C_1$  occurs very fast (less than 1 millisecond), it has little effect on the AC supply to  $L_{AC}$ .

- *Logic to control AC supply switch  $T$  ( $PL_{AC}$ ):* The second priority logic  $PL_{AC}$  is handled by  $CU$  as long as there is stable and sufficient DC voltage on the positive DC Rail ( $V_{dd}$ ) with respect to the DC ground rail ( $Gnd$ ).  $PL_{AC}$  is achieved by a set of control logic in  $CU$  which control the frequency to which control signal  $O_T$  is energized to actuate  $T$ . For example, to dim  $L_{AC}$ , the triac  $T$  is actuated later than when  $L_{AC}$  is at maximum brightness. To turn  $L_{AC}$  'off', the actuating signal on triac  $T$  is removed so that triac  $T$  is in high-impedance, non-conducting state.
- *Logic to handle Soft-touch switch actions ( $PL_{Soft}$ ):* The third priority logic  $PL_{Soft}$  is to handle localized switching and dimming functions through the use of a soft-touch push-button switch  $S_S$  as illustrated in Figure 1. Unlike a hard switch whereby its use necessarily mean the closing or opening of a physical contact, a soft switch like  $S_S$  is connected to one of  $CU$ 's input port pin. Therefore,  $S_S$  act like a sensor or detector to  $CU$  for  $CU$  to sense the push-button action and translate it to the right actuating signal to actuate the AC load  $L_{AC}$  accordingly. With the use of a soft-switch like  $S_S$ , several different switch functions can be achieved with just a single push-button assembly. Specifically, associated with the current invention,  $PL_{Soft}$  contain
  - control logic to sense whether the soft switch  $S_S$  is pressed with a short quick action and this is interpreted as an on/off command, and
  - control logic to sense whether the soft switch  $S_S$  is pressed with a long persistent action and this is interpreted as a dimming command.
- *Logic to communicate and interact with Auxiliary DC Device(s) ( $PL_{Aux}$ ):* The fourth priority logic  $PL_{Aux}$ , made up of the remaining processing capabilities of  $CU$ , is used to communicate and interact with auxiliary devices. Some of the more popular auxiliary DC devices may include IR/radar/temperature detectors, movement detectors, or light level or security detectors. For example in Figure 1, a DC wireless receiver auxiliary device is illustrated. After receiving RF commands from the remote controller, the TX/RX device  $L_{DC}$  informs  $CU$  of the commands received. Subsequently, the  $CU$  actuates the traic  $T$  appropriately and

then informs the TX/RX device  $L_{DC}$  to transmit an acknowledgment frame back to the remote controller. Since the first priority logic  $PL_{DC}$  and the second priority logic  $PL_{AC}$  is directly related to the frequency of the AC supply, i.e. 50/60 Hz, while  $PL_{Soft}$  is only needed on rare occasions (when a user is using the soft switch  $S_s$ ), 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 two-wire switch circuit of Figure 1 are still unclear. For example, at initial start-up, charge reservoir  $C_1$  is empty and thus is incapable of powering up  $CU$ . Since  $CU$  is not powered up, it is incapable of actuating control signal  $O_{DC}$  to replenish the reservoir capacitor  $C_1$ . The next section provides more details of the DC-charge-switch  $S_E$  and explains several important characteristic of the  $CU$  IC that allows for a smooth start-up of the current invention. Thereafter, details of priority logics  $PL_{DC}$  and  $PL_{AC}$  are provided to complete the picture.

## 2.2 Detailed Circuit Specification

Figure 2 illustrates the details of the preferred embodiment of the current invention. 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

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

5 The rest of the detailed explanations are provided in the following sections.

### 2.2.1 Triac actuating sub-circuit for AC supply to $L_{AC}$

In Figure 2, the sub-circuit consisting of  $R_6$ ,  $R_7$  and  $R_8$  and optocoupler  $U$  form the sub-circuit for actuating triac  $T$  in the first and third quadrant. When triac  $T$  is actuated, AC current is supplied to the AC electrical load  $L_{AC}$ . To actuate  $T$  into  
10 conducting AC current,  $CU$  generates a short pulse at pin  $O_{T,1}$  causing optocoupler  $U$  to conduct a **momentary** gating voltage to turn  $T$  on. As long as there is a potential difference between connection points  $MT_1$  and  $MT_2$  when the momentary gating voltage is applied, triac  $T$  conducts current. When the potential difference between  $MT_1$  and  $MT_2$  drops to zero (i.e. AC half cycle has completed) and there is no gating pulse applied, triac  
15  $T$  stops conducting. Therefore, for the triac to continue conducting in the next and future half cycles, a momentary gating pulse is required to be applied after every zero crossing point of the AC supply. For this purpose therefore, AC supply zero crossing feedback signal  $D_{zc}$  is used by  $CU$  to determine the right time to apply a gating pulse to turn triac  $T$  on. ***It should be noted that when  $T$  is already conducting, it is not possible to change***  
20 ***the state of  $T$  to be non-conducting (i.e. turn triac  $T$  'off') immediately.*** Only when there is no gating voltage applied **and** no potential difference between  $MT_1$  and  $MT_2$ , then triac  $T$  is able to latch to its non-conducting (i.e. 'off') state. The zero crossing feedback signal  $D_{zc}$  can be connected to a voltage comparator input of  $CU$ . If there is no voltage comparator input, any normal input port pin of  $CU$  will suffice as well. Both  
25 input options (i.e. either voltage comparator input or normal input port pin) will enable  $CU$  to sense whether  $D_{zc}$  is above or below a positive voltage reference either equal to  $V_{ref}$  or approximately equal to  $V_{ref}$ . In many commercially available  $CU$  devices,

$V_{ref} \approx 1-3$  volts, which is close enough to qualify as the zero crossing threshold, since AC peak voltage magnitude ranges from 140 – 325 volts.

## 2.2.2 Voltage divider sub-circuit

In Figure 2, the voltage divider sub-circuit consisting of  $R_{Div,1}$  and  $R_{Div,2}$  is required to produce a voltage level that is some fraction of  $V_{DD}$ . Thereafter, the said voltage level is used as the  $D_{DC}$  signal and connected to one of  $CU$ 's voltage comparator input pins, i.e.  $V_{cmp,DC}$ . The main reason for using a fraction of  $V_{dd}$  as the  $D_{DC}$  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 2, it is noted that the values of  $R_{Div,1}$  and  $R_{Div,2}$  is chosen such that  $\frac{R_{Div,1}}{R_{Div,2}} = \frac{V_{ref}}{V_{CU,Op}}$ . In addition, resistor values of  $R_{Div,1}$  and  $R_{Div,2}$  should be large such that power dissipation in the voltage divider sub-circuit is negligible. Hence, when  $D_{DC}$  drops below  $V_{ref}$ , it signals to  $CU$  that  $V_{DD}$  is below  $V_{CU,Op}$ . Conversely, when  $D_{DC}$  rises above  $V_{ref}$ , it signals to  $CU$  that  $V_{DD}$  is above  $V_{CU,Op}$ .

### 2.2.3 DC-Charge-Switch sub-circuit

Figure 2 also illustrates the preferred embodiment of the DC-charge-switch sub-circuit consisting of electronic solid-state switching elements in the form of PNP transistor  $Q_1$  and NPN transistor  $Q_2$ . Supporting  $Q_1$  and  $Q_2$  are resistors  $R_2$ ,  $R_3$ ,  $R_4$  and  $R_5$ . There are several important features of the DC-charge-switch sub-circuit and they are now explained as follows:

- In regard to transistors  $Q_1$  and  $Q_2$ , they are common-emitter transistor switches (since their controlled circuit is on their collector side).
- It should be noted that when  $Q_2$  conducts (i.e. 'on'),  $Q_1$  conducts charging current to the charge capacitor  $C_1$ . Conversely, when  $Q_2$  is 'off',  $Q_1$  is also 'off'. Since the states of  $Q_1$  and  $Q_2$  are *exactly in tandem*, they can be considered as a single electronic switch block as illustrated in the block diagram of Figure 1.
- Another important factor in regard to the DC-charge-switch sub-circuit is the initial start-up process associated with  $CU$ . As mentioned earlier, at initial start-up, charge reservoir  $C_1$  is empty and thus is incapable of powering up  $CU$ . Since  $CU$  is not powered up, it is incapable of actuating control signal  $O_{DC}$  to replenish the reservoir capacitor  $C_1$ . Now, to overcome the initial start-up dilemma, an important point should be noted in regard to  $CU$ :
  - The  $O_{DC}$  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  $CU$ 's 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  $V_{dd} = 0$ ,  $O_{DC}$  is a high impedance path (since  $CU$  is not in operation). Therefore current flow into  $R_4$  will avoid the  $O_{DC}$  path and instead flow into  $R_5$  and into the base of  $Q_2$ . This causes  $Q_2$  to conduct, drawing current out of the base of PNP transistor  $Q_1$ . Subsequently,  $Q_1$

conducts causing the charge reservoir  $C_1$  to charge up. Once the charge-up voltage in  $C_1$  exceeds  $V_{CU,min}$ ,  $CU$  starts operating and the control logic in  $CU$  now takes over the control of the DC-charge-switch actuating signal  $O_{DC}$ . 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  $C_1$  is proportional to the 50/60 Hz AC supply source, therefore, when the charge voltage in  $C_1$  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  $O_{DC}$  before the charge voltage in  $C_1$  exceeds  $V_{CU,max}$ .

- When  $CU$  is in operation (and in control of  $O_{DC}$ ), the DC-charge-switch sub-circuit is either closed (i.e. 'on') or opened (i.e. 'off') depending on the  $CU$ 's output voltage on pin  $O_{DC}$ . 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  $D_{DC}$  has exceeded  $V_{ref}$ ,  $CU$  outputs a 'low' (i.e. 0 volts) on  $O_{DC}$ , thereby causing current to be drawn away from the base of  $Q_2$  shutting off  $Q_2$ . This also removes base current from transistor  $Q_1$  causing  $Q_1$  to stop conducting. The voltage in the charge reservoir  $C_1$  now depletes as  $CU$  and auxiliary DC devices are still drawing DC supply. Another possible stop-charge operation can be described as follows: When it is sensed that  $D_{DC}$  has exceeded  $V_{ref}$ , rather than shutting off  $Q_1$  and  $Q_2$  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  $C_1$  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  $O_{DC}$ , thereby shutting off  $Q_1$  and  $Q_2$ . The second stop-charge operation provide 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 three conditions are satisfied: (1)  $CU$  is currently in the stop-charge state (i.e. both  $Q_1$  and  $Q_2$  are not conducting), (2)  $D_{DC}$  has dropped below  $V_{ref}$ , and (3) the AC supply switch, triac  $T$ , is non-conducting. The first two conditions are rather straightforward while the third condition is required because when the triac  $T$  is conducting (so that the electrical load  $L_{AC}$  is 'on'), an extremely low impedance path (almost short circuit) is formed between connection points  $MT_2$  and  $MT_1$  of Figure 2. Consequently, the  $BR$  circuit is unable to harvest adequate current to provide for DC harvesting. Hence all begin-charge operation must be coordinated with triac  $T$  in the 'off' state. However, a triac 'off' operation is not so simple as just removing the actuating signal  $O_T$ . As mentioned earlier, when triac  $T$  is already conducting, the only way for triac  $T$  to be turned 'off' is to not apply the triac gating voltage and to also wait for the voltage potential across  $MT_2$  and  $MT_1$  to go to zero. To simplify the coordination process (so that control logic in  $CU$  is also simplified), all begin-charge operation, if required, is initiated only at zero crossing points of the AC supply as it is only at these occasions where triac  $T$  can be assured to be 'off'. Of course, if triac  $T$  is already 'off', the begin-charge process can begin immediately without waiting for the zero crossing condition to occur. However, since the charge reservoir  $C_1$  must be designed to be large enough to provide reliable DC power for the longest period that triac  $T$  may be conducting and cannot be turned 'off', the situation where triac  $T$  is already 'off' can also be treated as if triac  $T$  is currently 'on'; this simplifies the begin-charge control logic for  $CU$ . In summary, when it is determined that  $D_{DC}$  has dropped below  $V_{ref}$ , at the next  $D_{ZC}$  zero crossing, no triac gating voltage is applied so that triac  $T$  is able to latch to its 'off' state. Thereafter,  $CU$  proceeds to output a 'high' on pin  $O_{DC}$  which turns on  $Q_2$  and subsequently,  $Q_1$ . Charging current flows into  $C_1$  via  $Q_1$  and  $R_1$ . When the

charge reservoir  $C_1$  is replenished, the stop-charge process (as described earlier) is initiated.

### 2.3 Details of Priority Logics $PL_{DC}$ and $PL_{AC}$

For convenience, the following symbol and its meaning is provided as follows:

- 5  $Cmd(x, Dim)$ : Command issued by a human user of the current invention, where  $x$  represents either ‘On’ or ‘Off’ and  $Dim$  represents the dim level, say 0 to 7, which applies only when  $x = \text{‘On’}$ .

For example,  $Cmd(\text{‘On’}, 0)$  is a command issued to the current invention by a human user intending the electrical load  $L_{AC}$  of Figure 2 to be supplied with maximum AC power (since  $Dim = 0$ ). In another situation,  $Cmd(\text{‘On’}, 7)$  intends the electrical load  $L_{AC}$  of Figure 2 to be supplied with minimum AC power so that maximum dimming effects are experienced. Conversely,  $Cmd(\text{‘Off’}, don't\ care)$  intends electrical load  $L_{AC}$  to be turned off. The origin of  $Cmd(x, Dim)$  is primarily due to priority logics  $PL_{Soft}$  and  $PL_{Aux}$  which handle human interaction either through the soft-touch switch  $S_s$  or through an auxiliary DC powered wireless chip as illustrated in Figure 2. Of course, there should be no limitations to amount of command parameters that can be provided by the current invention. For the purpose of facilitating explanation for priority logics  $PL_{DC}$  and  $PL_{AC}$ , it is assumed the bi-tuple command  $Cmd(x, Dim)$  is being used.

20 The details of  $PL_{DC}$  and  $PL_{AC}$  is best explained through the use of Figure 3 which illustrates the well-known sinusoidal time waveform of the AC supply presented at connection point  $MT_2$  of Figure 2. It is assumed that some time prior to the first half-cycle, a user command  $Cmd(\text{‘On’}, Dim)$  was received (either through  $PL_{Soft}$  or  $PL_{Aux}$ ). Subsequently,  $PL_{DC}$  and  $PL_{AC}$  are required to ensure sufficient DC harvesting as well as providing AC supply to the electrical load  $L_{AC}$ .

25 The work of  $PL_{DC}$  takes place just after every zero crossing point of the AC supply (which can be detected by  $CU$  via signal  $D_{zc}$  in Figure 2). As mentioned before, when the AC supply potential across the triac  $T$  goes to zero, the triac  $T$  does not conduct

(as marked on every  $ZC$  point of Figure 3). Using this opportunity,  $PL_{DC}$  proceeds to close the DC-charge-switch  $S_E$  by outputting a ‘high’ voltage on  $O_{DC}$ . DC charge reservoir  $C_1$  is subsequently replenished. The charging time of  $C_1$  is illustrated in the shaded  $DCH$  regions of Figure 3. The  $DCH$  regions are characterized by  $T$  being ‘off’ and  $S_E$  ‘on’. During the  $DCH$  periods, signal  $D_{DC}$  is sensed by  $CU$  so that after some time, i.e. at the  $CF$  (Charge Full) points of Figure 3,  $PL_{DC}$  has to open the  $S_E$  switch to prevent overcharging. This completes the  $PL_{DC}$  priority logic for DC harvesting. It should be noted if it is sensed that  $D_{DC}$  has not dropped below  $V_{ref}$  (where  $V_{ref}$  is defined in section 2.2.2),  $PL_{DC}$  does **not** perform DC harvesting (although it is shown in Figure 3 that after every  $ZC$  point, DC harvesting takes place). While it is acknowledged that some amount of AC power is used for DC harvesting at the beginning of every AC half cycle, the amount used is negligible and does not affect the power to the electrical load  $L_{AC}$ .

After the  $DCH$  periods, the work of  $PL_{AC}$  takes over to actuate the AC load  $L_{AC}$ . As illustrated in Figure 3,  $PL_{AC}$  caters first for a  $Dim$  period, characterized by  $T$  and  $S_E$  both in the ‘off’ state. The higher the  $Dim$  level requested by the user, the longer the  $Dim$  period so that the desired fraction of the full AC power is delivered to the electrical load  $L_{AC}$ . After the  $Dim$  period, the triac  $T$  is actuated to deliver the rest of half cycle power to  $L_{AC}$ . At the next zero crossing point, triac  $T$  stops conducting and the same process repeats.

Figure 3 also illustrates that at some time point in the 3<sup>rd</sup> half cycle, a user command  $Cmd$ (‘Off’, *don’t care*) was received. In this case, in the following half cycle (4<sup>th</sup>) and above, after the usual DC harvesting  $DCH$  periods,  $PL_{AC}$  does not actuate the AC supply switch (i.e triac  $T$ ).

## 2.4 Scalable Circuit Specification

As mentioned earlier, the current invention is also scalable whereby a multitude of AC loads can be controlled using the same base architecture with minimal component additions. Figure 4 illustrates the preferred embodiment of the current invention when used to control a multitude of AC loads. Figure 4 illustrates the circuit embodiment for

the control of two AC loads but it should be clear to persons skilled in the art that similar connections can be added to control more than two AC loads. As illustrated in Figure 4, scaling up the circuit to cater for the control of several AC loads involves the addition of another triac device and another opto-coupler for triggering the triac device. The rest of the circuit involves connections to available I/O pins in the  $CU$  unit and thereafter, a control logic update to  $PL_{AC}$  so that the  $CU$  is now able to actuate multiple AC supply triacs. It is noted that there is no additional circuitry required for the base circuit (consisting of  $BR$ ,  $S_E$ ,  $R_1$ ,  $C_1$ ,  $CU$ ,  $R_{Div,1}$  and  $R_{Div,2}$ ) that provide for the switch-mode DC harvesting process.

## 2.5 Additional Protection Circuitry

Additional protection circuitry can also be added to the preferred embodiments (i.e. Figure 2 and Figure 4) of the current invention. Figure 5 illustrates these protection circuits when included in the simpler circuit diagram of Figure 2. In Figure 5, a fuse  $F$  is added on the Active wire supply which limits the maximum AC current through the current invention. A snubber circuit consisting of  $C_2$  and  $R_{12}$  can be added to enhance the switch-off reliability of triac  $T$ , particularly in the situation  $L_{AC}$  is an inductive load, e.g. a fluorescent light. In recent times, snubberless triacs are also commercially available which do not require the aid of snubber circuits. Also included in Figure 5 is a bi-directional TVS (Transient Voltage Suppressor) diode  $D_{TVS}$  connected in parallel to  $T$ . The use of  $D_{TVS}$  is to suppress unwanted voltage spikes which may affect the operation of triac  $T$ . 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  $CU$  as illustrated in Figure 5. The Zener breakdown voltage rating in  $D_{Zener}$  should be chosen high enough such that  $D_{Zener}$  does not break down when  $CU$  is operating normally. 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 clear to experts skilled in the current art that similar types of protection circuitry can also be added to the (more complicated) circuit embodiment illustrated in

Figure 4 (which handles multiple AC loads). It is noted that the protection circuitry illustrations in Figure 5 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.

## 5    **2.6 Other Circuit Realizations**

While Figures 2, 4 and 5 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 switch-mode DC harvesting in the described two-wire switch scenario and it is not intended to be restrictive. Examples of some of these trivial variations are now presented. For example, Figure 6 illustrates a DC-charge-switch variation of Figure 2 where NPN transistor  $Q_1$  is fitted to the  $Gnd$  rail and  $CU$  triggers PNP transistor  $Q_2$ . Both  $Q_1$  and  $Q_2$  transistor switches are all operating in the common-emitter switch mode be it in Figure 2 or in Figure 6. It is clear that Figure 2 and Figure 6 are equivalent and only demonstrates a preference with no particular inventive step. Further trivial variations are also possible whereby in Figure 7, a half-wave rectifier is used. In that case, it should be clear to experts skilled in the present art that the charging capacitor  $C_1$  in Figure 7 should have larger storage capacity than  $C_1$  of Figure 2. Also shown in Figure 7 is another method of triggering the AC power triac  $T$  by using one of  $CU$ 's output pins to actuate  $T$  directly rather than through an opto-coupler (as illustrated in Figure 2). In that case, triac  $T$  is triggered in its first and second quadrant. Another trivial variation involve replacing the DC-charge-switch sub-circuit  $S_E$  with a single break contact electronic IC switch (i.e. when there is no power, the said electronic IC switch conducts) as illustrated in Figure 8. Another possible variation is to replace transistors  $Q_1$  and  $Q_2$  (of Figure 2) with equivalent MOSFET devices.

In summary, it is important to note that a useful two-wire AC supply switch, providing switch-mode DC power supply to a multitude of DC powered IC chips, thereby

enabling more options for switch control, in particular remote control operation, for possible use in a wide application field, and with a high possibility that a large number of trivial circuit variations can be used to replace or add to its preferred form, has been disclosed.

### 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.
- [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 2003.

# Claims

1. A two-wire AC switch comprising: means for switching AC power supply (to an AC load connected in series to the said switch circuit), an actuating circuit for effecting the said AC supply switching means, the said actuating circuit comprising of a software/hardware programmable DC-powered controller unit with input/output facilities for sensing/outputting signals as well as handle external user inputs and translate them to appropriate AC supply actuation, a switch-mode DC harvesting circuitry which is also controlled by the said controller unit via the utilization of a small portion of overall AC supply, so that sufficient DC power is harvested to not only power the said controller unit but also a multitude of DC auxiliary devices.
2. A two-wire AC switch as claimed in claim 1, wherein a power triac, connected in series to the AC load, is used as the said means for switching AC power supply..
3. A two-wire AC switch as claimed in claim 2, wherein the gate input to the said power triac comprises of a connection to an opto-coupling switch device whose LED input is controlled by the said DC-powered controller unit.
4. A two-wire AC switch as claimed in any one of claims 1 to 2, wherein the gate input to the said power triac is directly controlled by the said DC-powered controller unit.
5. A switch-mode DC harvesting circuit as claimed in claim 1 wherein the circuit is connected in parallel with the said AC supply switching means.
6. A switch-mode DC harvesting circuit as claimed in claim 5 wherein the circuit is able to not only supply adequate DC power the said DC-powered controller unit, but also supply adequate DC power to power a multitude of DC-powered auxiliary devices that handle additional switch control signals over and above conventional manual switch signals.
7. A switch-mode DC harvesting circuit as claimed in claims 5 to 6, wherein the circuit comprises a full-wave or half-wave rectifying circuit.
8. A switch-mode DC harvesting circuit as claimed in claims 5 to 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 controller unit to enable the said DC-powered controller unit to monitor DC and AC signals in order to control the said 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 connection means, as claimed in 8, for the purpose of controlling switch-mode DC harvesting by the DC-powered controller unit, wherein one DC feedback signal and one AC zero-crossing feedback signal is provided as input to the said DC-powered controller unit.
- 15 11. An AC and DC output control means, as claimed in 8, for the purpose of controlling switch-mode DC harvesting by the DC-powered controller unit, wherein one output signal from the DC-powered controller unit is used to close or open the DC-charge-switch as claimed in 9 and another output signal from the DC-powered controller unit is used in the actuation of the power triac as claimed in 1 to 3 and where these controls are to be coordinated with the AC supply zero-crossing point which is made available by the AC zero-crossing feedback signal as claimed in 10.
- 20 12. A first priority control logic governing the switch-mode DC harvesting behavior of the said DC-powered controller unit, wherein the logic first checks for an AC zero crossing point via the AC zero-crossing feedback signal (claimed in 10), and then, depending on the magnitude of the DC feedback signal (claimed in 10), makes an exclusive decision whether to leave open the DC-charge-switch (claimed in 9) and terminate, or close the said DC-charge-switch so as to enable charging current into the DC charge reservoir (claimed in 8) before opening again the said DC-charge-switch when the DC charge reservoir is full and then terminating.
- 25 13. A second priority control logic governing the AC load actuating behavior of the said DC-powered controller unit, wherein the logic, applied immediately after the termination of the first priority logic (claimed in 12), handles the delay before the
- 30

actuation of the AC load in order to satisfy a user dimming requirement, and thereafter decides whether to actuate or not actuate the power triac, claimed in 2 and 3, depending on the current switch state decided by the user.

- 5 14. A third priority control logic governing the soft-switch actuating behavior of the said DC-powered controller unit, wherein the logic, either applied immediately after the termination of the second priority logic (claimed in 13) or as an interrupt process, handles the different types of user inputs made possible through the use of a push-button switch which is connected to an input of the said DC-powered controller unit, so that the push-button switch behaves more like a sensor device (rather than just a  
10 conventional on/off switch) for sensing various push-button actions.
- 15 15. A multiple AC load switch, for the purpose of controlling multiple AC loads, derived from the two-wire AC switch as claimed in claims 1 to 4, via just the addition of an additional power triac circuitry and triac actuating connections to the same said DC-powered controller unit for each additional AC load to be controlled.
- 15 16. A two wire switch circuit as claimed in claims 1 to 4, wherein the circuit further comprises a snubber circuit connected in parallel to the power triac as claimed in 2 and 3, for the purpose of mitigating unexpected triac operations.
- 20 17. A two wire switch circuit as claimed in claims 1 to 4 and claim 16, wherein the circuit further comprises a bi-directional transient voltage suppression diode (and the like) connected in parallel to the power triac as claimed in 2 and 3, for the purpose of mitigating unexpected voltage spikes.
- 25 18. A two wire switch circuit as claimed in claims 1 to 4, 16, and 17, wherein the circuit further comprises a zener diode (and the like) operating just below its breakdown voltage, connected in parallel to the said DC-powered controller unit as claimed in any of the preceding claims, so as to mitigate unexpected overcharge scenarios.
19. A switching circuit substantially illustrated in all the accompanying drawings and substantially described via reference to the said accompanying drawings.