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VOLTAGE REGULATION OF UNINTERRUPTED POWER SUPPLIES

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RINGKASAN: *Sistem Bekalan Kuasa Tidakterganggu (UPS) digunakan sebagai satu penyelesaian masalah kualiti kuasa dan untuk memberikan perlindungan terakhir kepada gangguan kuasa seperti terputus bekalan kuasa. Kebanyakan sistem UPS mengalami keadaan di mana keluaran peraturan voltan teruk, terutamanya dengan beban yang berat. Tujuan kerja ini adalah untuk merekabentuk dan melaksanakan sistem UPS yang dapat menghasilkan keluaran bekalan* $230V_{ac}$*, 50Hz yang tetap dan berterusan. Gegelung suapbalik telah dilaksanakan menggunakan pengawalmikro untuk melaraskan tahap bekalan dc pada penyongsang UPS. Ujian telah dilakukan untuk mengenalpasti keboleharapan dan keberkesanan sistem yang telah direkabentuk dan keputusan yang baik telah diperolehi dalam memperbaiki peraturan voltan.*

ABSTRACT: Uninterrupted Power Supply (UPS) systems are used as a solution to power quality problems and to provide ultimate protection for power disturbances such as power blackouts and brownouts. Many UPS systems suffer from poor output voltage regulation especially with heavy loads. This work is aimed to design and implement the UPS system capable of producing continuous and constant $230V_{ac}$, 50 Hz output supply. A feedback loop has been implemented using microcontroller to adjust the dc level supplying the UPS inverter. Tests have been carried out to determine the reliability and effectiveness of the designed system, and good results have been obtained in improving the voltage regulation.

KEYWORDS: UPS, voltage regulation, batteries, power continuity, AMF

INTRODUCTION

Electric power has emerged as one of the most important elements in our daily livelihood in recent years. Power interruption leading to various outcomes has been experienced and is proven to be a threat to power consumers especially in large industries. Losses in terms of life, financial and productivity are the most common aftermath of power interruption. Hence, a smart power back-up and protection system has been developed. It is known as Uninterrupted Power Supplies (UPS) that provides solutions for failure of utility to maintain power supply.

In practice, there are critical or essential loads which have to be kept running all the time either in industries or applications. Therefore, slight interruption in power supply will be a major blow and may result in all sorts of uninvited effects. Uninterrupted Power Supplies (UPS) are used to supply clean and uninterrupted power to critical loads, such as computers, medical/life support systems, communication systems and industrial controls (Jou *et al*, 1995). This is done under any normal or abnormal utility power conditions, including outages from a few milliseconds up to several hours duration. The hold-up time is totally dependent on the size of the critical load and the energy-storage capabilities built in the UPS, which can support this critical load. In order to supply output power in the absence of the input power, the UPS employs some form of bulk energy-storage mechanism. Most UPS systems use valve-regulated lead-acid batteries or glass matte starved electrolyte batteries for this purpose (Chiang *et al*, 1995). These maintenance-free batteries are the most widely used as energy-storage devices because of their portability and low maintenance requirements.

In industries, the UPS is normally employed along with the standby generator set, but in general the UPS systems are designed in such a way to be used as a short-term back-up supply to maintain continuity of power (Kawabata *et al*, 1989). Power continuity is very important in certain industries such as in hospitals (for powering the operation theatres, Intensive Care Units (ICU) and medical equipment) and airports (for continuity of communication between aircraft and communication towers and radar system etc).

One of the main drawbacks of the UPS system is its inability to supply power for longer period during main supply interruption. Since battery takes over as power source during utility interruption, therefore batteries of larger rating (larger A-h rating) is required to extend its duration of operation during main failure (Kwon *et al*, 2001 and Hsu,1996).

In large industrial applications, UPS is commonly used as a backup supply only for short periods of not more than few minutes whenever the main supply is interrupted before standby generator operates. This is due to the fact that standby generator has to crank start and has to reach a steady state before they are able to take over or support the system (Cosse *et al*, 2001). Crank starting of generator contributes to slight delay, practically in the region of 15 seconds at the most. Hence, with an implementation of UPS into the system, the 15 seconds of interruption could be taken over by the UPS. With this kind of implementation, continuity of power supply is guaranteed.

Automatic Mains Failure (AMF) is the control system that detects failure of the main supply and generates control signal to crank start the standby generator, to open switch 1 and close switch 2 (Figure 1) after 15 seconds delay to maintain continuity of the supply. Figure 1 shows Switch 1 and Switch 2 both interlocked. Switches 1 and 2 are high-speed transfer switches that are able to open and close contact in microseconds to nanosecond range (Kejuruteraan Bintai).

Modern UPS system that is available nowadays, whether used in high power or low power application, records improvement from its ancestors. Most of the upgrades are done on the harmonics elimination, power factor improvement, protection against short circuit, overloading and automatic voltage regulation (Rashid, 1993).

In this paper, the study and test are mainly focused on the online type UPS with a general configuration shown in Figure 2, which has an inverter that operates continuously, and its output is directly connected to the essential loads. This configuration requires no circuit breaking time. At normal operation, the rectifier functions as a battery charger to maintain full charge of the battery. During normal operation, when the main supply is in good condition, both the rectifier and inverter operate at the same time. Main feature of this system is that it provides protection from transient in the main supply and is able to maintain load frequency at desired value. The path to the normally off transfer switch is bypassed in the hardware implementation. Same circuit of Bulk chopper and feed back can be applied to control the output voltage for three phase inverter.

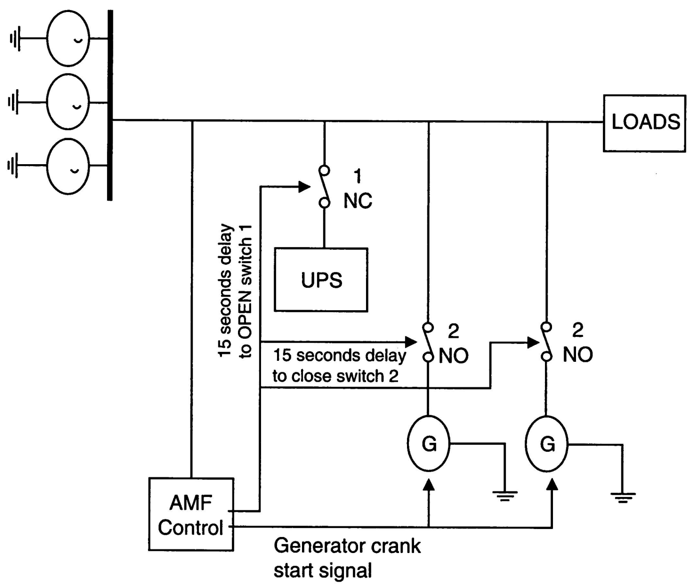

Figure 1. *UPS implementation in power system with AC mains interfacing c/w generating set support*

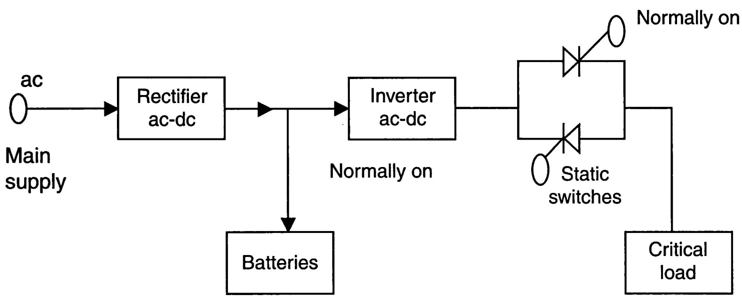

Figure 2. *Typical block diagram for online UPS system*

DESIGN METHODOLOGY

Hardware Design

The circuit design shown in Figure 3 is used to convert the AC supply from the main supply into DC to charge the battery pack and also as input voltage to the Buck regulator. Buck regulator output is made variable by adjusting the firing duty cycle. Regulated DC output is then fed into an inverter for DC - AC conversion. The band pass- filter will be tuned to 50 Hz so that this signal is impressed across the step-up transformer. As can be seen from Figure 3, when the main supply fails, the battery pack will take over in order to supply power to the load.

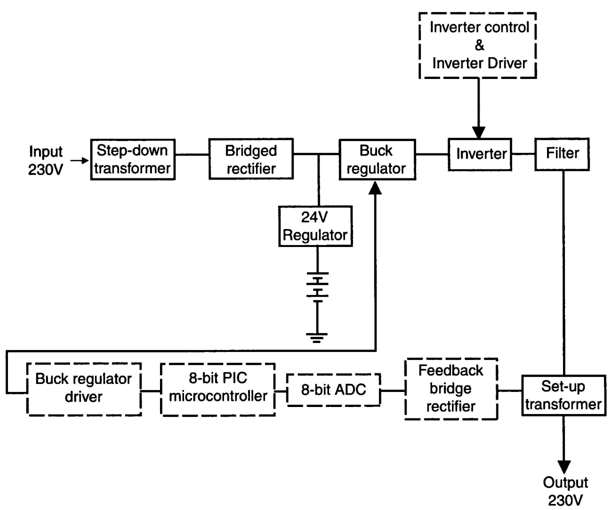

Figure 3. *Overall block diagram of the proposed system design with feedback control*

Since the inverter is a free-running inverter (works all the time), therefore by controlling the firing duty cycle of the Buck regulator, the output voltage of the inverter is made variable. In general, the 'Automatic Output Voltage Regulation Feedback' has been employed to maintain inverter output at 12 V_{ac}. If the primary winding of the step-up transformer is somehow maintained at 12 V_{ac}, the secondary output should be in the region of 230 V_{ac}. If the detected inverter output voltage, V_p of Figure 3 is lower than 12 V_{ac}, then the 'Automatic Output Voltage Regulation' system will act to increase the PWM duty cycle of the Buck regulator so that the output of the inverter will increase as well. However, if the detected value of V_p is higher than 12 V_{ac}, then the microcontroller will reduce the PWM firing duty cycle of the Buck regulator in order to reduce the output voltage of the inverter.

Software Development

Referring to the flow chart in Figure 4i and Figure 4ii, a total number of **N** = 69 loops is assigned to denote 100% duty cycle. Another variable denoted by DUTY corresponds to the current duty cycle. If the value of DUTY is 40_{10}, then the duty cycle is set at 40/69 X 100%. A HIGH - level output at RA0 is held for a total of DUTY loops at subroutine HIGH_LOOP before RA0 is set to LOW level. RA0 will be held LOW for a total of (N - DUTY) loops in subroutine LOW_LOOP right after the HIGH_LOOP. This is basically the principle of generating a PWM signal from the microcontroller. With **N** = 69, the generated PWM signal has a frequency of about 12.5 kHz and this value of frequency can be increased or decreased by changing the value of **N**.

At the end of each HIGH_LOOP and LOW_LOOP subroutine, the microcontroller will send out a $\overline{WR}/RDY$ signal to the 8-bit ADC to initiate analogue to digital conversion through RA1. About 1.5 ms after the initiation signal has sent out, the digital output from ADC is read into PORT B for corresponding duty cycle computation. In short, after completion of each HIGH_LOOP and LOW_LOOP, the output of ADC is scanned into PORT B of the microcontroller.

After scanning the digital output bits of the ADC into PORT B, the digital value read into PORT B is then compared with V_REF to determine whether the inverter output is maintained at 12 V_{ac}. Computation is made based on computed value of (V_REF - PORT B). Below are three possible values of reference voltage for port B (V_REF - PORT B):-

For (V_REF - PORT B) = 0,

- The current value of DUTY is maintained which means that the same number of HIGH and LOW level loops for RA0 is restored.

For (V_REF - PORT B) > 0,

- Value of DUTY will be increased by one, which means that RA0 will be held HIGH for one extra loop while LOW-level loop will be reduced by one loop. This corresponds to an increase in duty cycle.

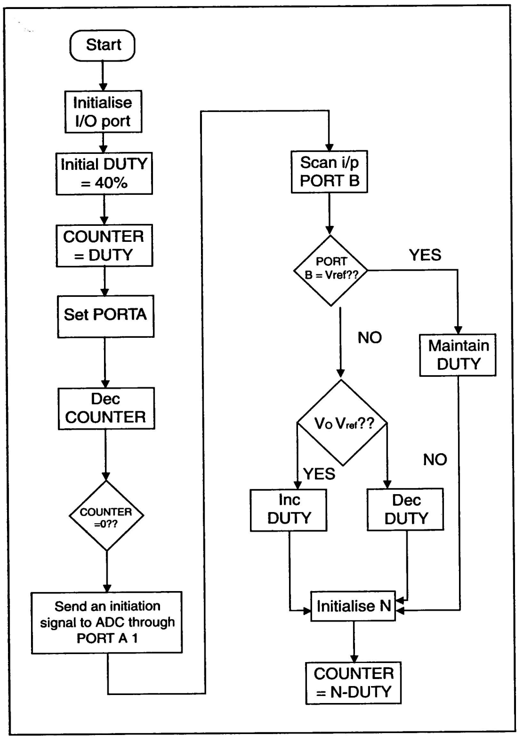

Figure 4i. Software control strategy flow chart

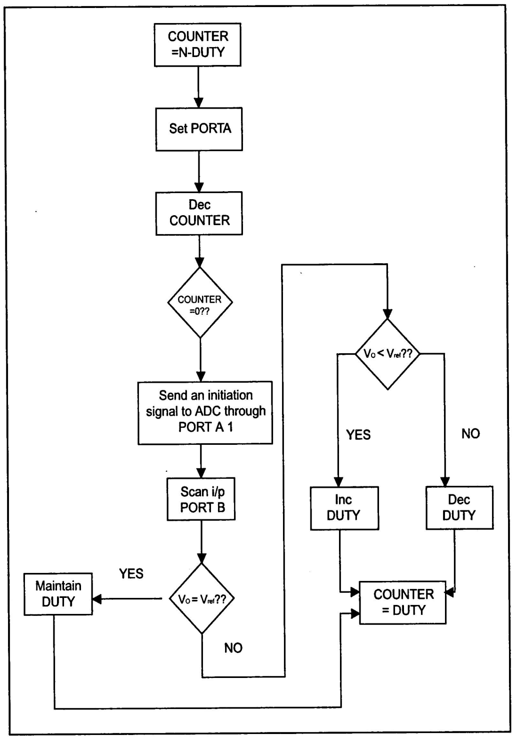

Figure 4ii. Software control strategy flow chart (continue)

For (V_REF - PORT B) < 0,

- Value of DUTY will be decreased by one, which means that RA0 will be held HIGH for one loop less while LOW-level loop will be increased by one extra loop. This corresponds to a decrease in duty cycle.

With a manual Buck regulator control, it is found that V_REF = 40_{16} corresponds to inverter output of 12 V_{ac}. Therefore V_REF = 40_{16} is the threshold value for a decrease or increase in duty cycle. The scanning of the ADC and mathematical computation process will keep repeating until the output of inverter is maintained at 12 V_{ac} that is equivalent to 40_{16} (equivalent to $1000\ 0000_2$) at the ADC output.

RESULTS AND DISCUSSION

Output Voltage without Automatic Control (open loop test).

An incandescent lamp of 100W is connected as load. During normal operation, the incandescent lamp lights up at its rated brightness. The power has been measured. When the main supply is cut-off, the continuity of power to the load maintained, however the incandescent lamp appeared to be slightly dimmer because the load voltage is not at its rated value of 230 V_{ac}. Figures 5 and 6 show the output voltage waveforms before and after main supply interruption.

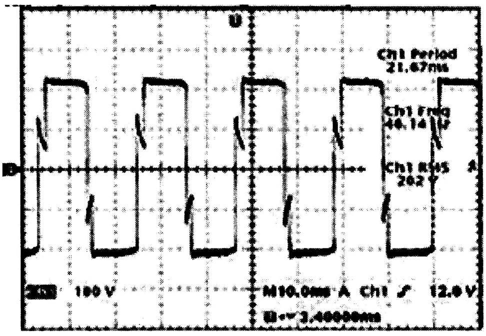

Figure 5. *Output voltage waveform before interruption of the main supply (without voltage regulation control)*

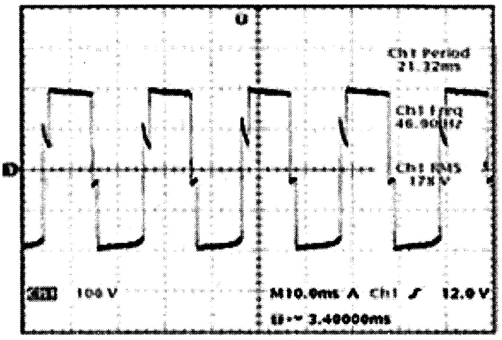

Figure 6. *Output voltage waveform after interruption of the main supply (without voltage regulation control)*

With Automatic Output Voltage Regulation Control (closed loop test).

The feedback loop has been added to the system to improve the stability of the output voltage. The hardware circuit of the feedback consists of voltage transformer (VT) to reduce the voltage, bridge rectifier to convert the signal to dc, which is easier in comparison, and micro-controller that generates continuous square pulses. The duty cycle of these pulses changes depending on the dc input voltage to the micro-controller. The software programme and flow chart has been explained in paragraph II.

Figure 7 shows the experimental waveform when the dc input voltage is less than V_REF. The microcontroller will respond by increasing the firing duty cycle of Buck regulator, while the duty cycle will decrease if the input voltage becomes more than V_REF, as shown in Figure 8.

Applying these pulses with changeable duty cycle to the gate of the chopper, a variable dc voltage could be obtained to adjust the out ac voltage. Figure 9 shows that the amplitude of the output voltage is constant. A small instantaneous reduction appears due to sudden change of the load.

Since the duty cycle can be changed to a wide range, the regulation of the output voltage could be adjusted automatically to keep the voltage with a certain limit. Figure 10 shows the voltage regulator of the system at different values of the load.

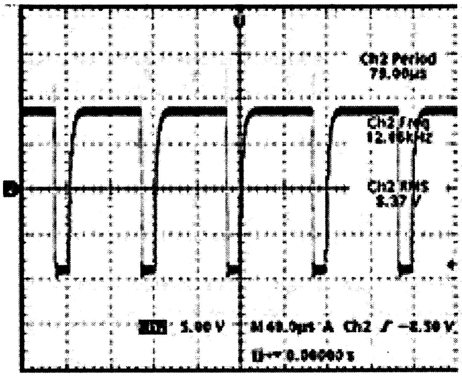

Figure 7. *Output waveform of Buck regulator driver for V_{in} < V_REF*

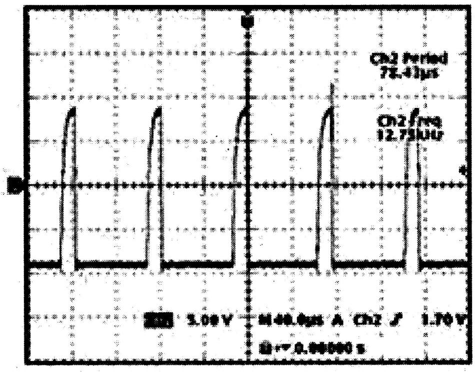

Figure 8. *Output waveform of Buck regulator driver for V_{in} > V_REF*

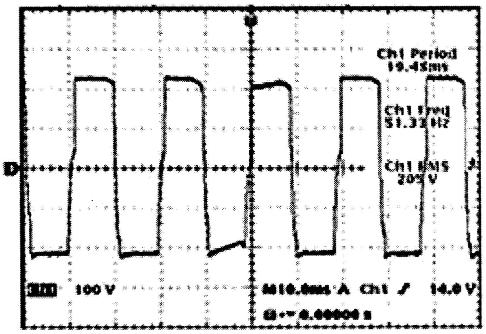

Figure 9. *Output voltage waveform with voltage regulation control*

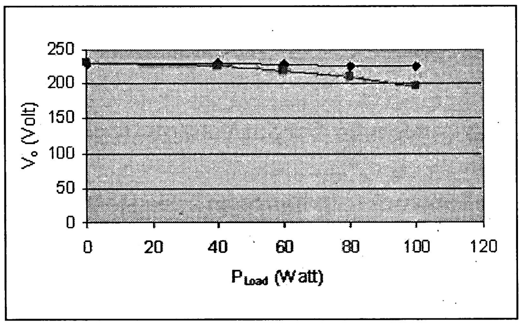

Figure 10. *Voltage regulator at different values of load with and without feedback control*

CONCLUSION

A complete hardware UPS single phase system has been developed and tested with and without voltage regulation control; microcontroller has been used to determine the input voltage of the Buck chopper, so as to keep the output of ac voltage at constant value. The required software of the microcontroller has also been developed to control the duty cycle value according to the input voltage, which came from the load. Good results have been obtained with automatic voltage regulation. The reliability and effectiveness of the system has been examined and the voltage regulation improved by using this system. This paper however does not cover the harmonics study. Harmonics study of the system will be done in future work to improve the system.

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