

ANALYTICAL MODELLING OF A DIGITAL KITCHEN TIMER

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Abstract

The paper looked at the benefits of energy conservation using a digital kitchen timer. A digital kitchen timer is a simple clock-work mechanism which triggers on upon the application of load. The design principle of the device was examined. The simple circuit was achieved using two analog-digital converters, two transformers and a NAND gate. The block diagram of the model digital kitchen timer shows that it has seven segment display and a memory cascaded with a comparator. The device is meant for domestic allocation of energy to minimize waste and the user can code in any amount of power provided that the keyed in figure does not exceed the main supply wattmeter.

Keywords

β – instrument measurement error
 U – peripheral speed
 R_A – ammeter resistance of the induction wattmeter
 V-F – voltage to frequency converter
 TA – current transformer
 TV – voltage transformer

1.0 Introduction

The capital intensiveness of power company services makes it necessary to make some efforts towards reducing wastes associated with our energy intake. The energy consumer should participate in estimating the power consumed indoors and in public places. This is where the digital kitchen timer comes in. The digital kitchen timer belongs to the first class measuring instrument when compared with the eight classes of measuring instruments namely: 0.05, 0.1, 0.2, 0.5, 1, 1.5, 2.5, 4 [1] at normal 220volts, 50 Hertz and accuracy depending on the quantity of energy consumed. The device has a permanent d.c. supply voltage which operates the various components of the timer when there is no light. It also has in-built memory wherein the consumer registers the quantity of energy required consumption at a given period of time. This makes the digital kitchen timer to operate on two modes – the display mode and the memory mode. The required quantity of energy will be keyed into the memory of the device, which will be clocked to work as a count-down clock piece as soon as load is applied at the terminals. This means that at any particular moment, the

consumer will know how many kilowatts of energy he has in reserve. The clock piece displays its content in a seven segment display arranged in series according to the desired capacity of the device. The accuracy is high and as the load increases, the rate of the count hastens. At no load, the device does not clock but displays the remaining part of the coded kilowatt. At the inception of the maximum load coded into the memory, the kitchen timer automatically cuts off the supply from the public power source. The fact remains that the instrument avoids unnecessary wastage of electricity and hence helping the government in her fight for energy conservation.

2.0 Theory of Wattmeter

(a) **The induction type:** Electrical measuring instrument and the parameters they measure include current (direct or alternating) measured with ammeter, voltage – voltmeter, active power – wattmeter, reactive power- varmeter, counters measure both direct and alternating current energy, frequency of alternating currents and waves – frequency meter, phase current shift or $\cos\phi$ – phase meter, resistance – ohmmeter, direct current and voltage – galvanometer and the modifications of galvanometer – the magnetic-vane attraction meter, the dynamometer and the repulsion-attraction types (for ac measurements) [2]. The analog wattmeter belongs to the group of measuring instruments known as indicators. The digital kitchen timer that will be discussed here belongs to the group of measuring instruments referred to as counters. Induction

type meters are used for a. c. while electro-dynamics and iron-core electro-dynamics are for measuring d.c. and moving-coil meters are used for measuring ampere-hour of stored energy, example battery.

Based on their principle of operation, electrical measuring instruments are subdivided into magneto electric and electromagnetic, electro-dynamics, induction, thermal and vibration instruments, thermoelectric, rectified instruments and instruments belonging to the analog group and the modern day analog-digital converters (AD converter) to which the digital kitchen timer belongs. All measuring instruments possess measurement error represented as β . This is the maximum amount of errors in measurement in percentage of maximum diversity factors α_{max} of the measuring scale. $\beta = (\alpha_m - \alpha_{max}) / \alpha_{ac}$, where α_m = measured quantity, α_{ac} = accurate quantity.

2.1 Short falls of the analog wattmeter

- (i) Independent emf is induced into the non magnetic metal disc as: $E = (2\pi k_1 \psi R n) / 60$, here n – revolutions per minute of the disc, R – the main radius of the disc within the magnetic pole, ψ – magnetic flux and k_1 – a const showing the ratio of current on the fixed coil and the current on the rotating plate. The emf which, is induced into the aluminum disc encourages the passage of eddy current in the disc. Though this current is necessary for the normal functioning of the wattmeter, yet, it wrongs the actual turning moment of the meter hence both the current and the emf were not produced by the electricity to be measured.
- (ii) There is the problem of friction in the register and in the jewel bearings. This reduces the sensitivity and accuracy of the meter. It may even fail to rotate if the friction is too much on the jewel bearings. By so doing, the meter may fail to do the work of measurement and registering of energy consumed. Since the compensating torque for the frictional force is independent of the load current, it follows that a constant and unaccounted current is drawn from the source irrespective of the load which, the consumer has to pay for. The end result of this presence of a constant compensating torque is that the meter may

'run away' – rotating continuously at no load. Again, for meters with compensating coil, the speed can be adjusted by altering the position of the retarding magnet and its sensitivity can be adjusted by altering the position of the friction compensating coil. The deflecting torque of an induction meter is proportional to the angular frequency ω , and $\omega = U/R$, where R – the main radius of the disc's part located between the magnetic poles and U – average peripheral speed of the disc's portion located between the magnetic field. The meter disc is made of aluminum, which has a large temperature coefficient of resistance and it is expected that a change of about 10°C in the disc temperature will change the deflecting torque by as much as 4% [3]. One more shortfall of the induction wattmeter and similar others is that almost all the load current passes through the wattmeter leaving the safety of the measuring instrument at the mercy of its internal resistance and probably a shunt resistance R_s . Again the whole parts of the instrument is left open for electric shock and at times have been the source of accidental grounding of electrical systems. When a shunt resistor is used for the connection of electrical systems, the ammeter current becomes less than the load current by the following proportions:

$I_A = I * R_s / (R_s + R_A)$, where R_A – ammeter resistance, R_s – shunt resistance and I – load current.

- (b) **Analog-to-digital:** The measuring instrument is fed from a rectified voltage through a step down transformer thereby separating load current from meter current. A coupled current transformer with fewer turns than the voltage transformer produces a voltage that is proportional to the load current. These two transformers produce d.c. voltage that are fed into the different analog-digital converters (ADCs). These ADCs convert the voltage signals to frequencies directly proportional to input voltages. The output from the ADCs are then fed into a 74LS11 together with a clock pulse from an NE555 timer in order to produce a final output that will be fed into pin 5 of the less significant counter. The use of the clock is

to enable the gate to produce an output only when a load is connected. The circuit of fig. 1 could have been simplified by using a voltage-controlled-oscillator NE555 and voltage-to-frequency converter TS9400 integrated circuit. This is a major achievement in the construction of a voltage, current and frequency dependent digital wattmeter [4].

The unique feature of this digital kitchen timer is that the estimated power to be consumed is

keyed into the device and clocked by direct loading. By so doing, a consumer knows how much energy at his disposal. This greatly enhances energy economy and prudent management. Once the keyed load is exceeded, the apparatus automatically cuts the load off from the supply. This measuring instrument will need a standby power source to retain the memory. A major component in the design of the device is the current transformer.

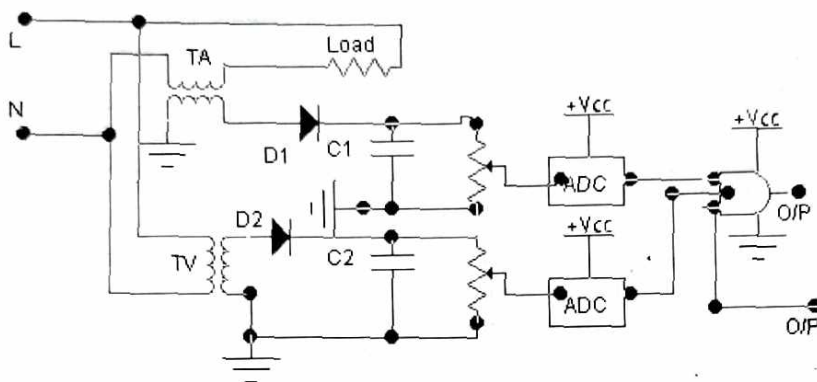


Fig. 1.0 Analog-to-digital converter

If the kitchen-timer is to work in up-down count, the required unit of power will be loaded in. The multiplexer permits the display of the content of either the clock or the register. The maximum energy to be used is keyed into the register. When this happens, the enable of the multiplexer is low while the data select is high, then the hour switch is continuously pressed until the desired number of kilowatt is input. When a load is connected to the device, the current and voltage transformers produce the pulse which drives the clock and the higher the load current, the faster the clock. In effect, the two input transformers to the analog-digital converters function as voltage transformers and the analog to digital converters convert the

voltages into proportional frequencies. These frequencies pass through the 74LS11 (3-input AND gate) that is triggered by an NE555 to give a combined frequency that enter into pin 5 of the counter. The counter starts incrementing the energy as long as the load is connected and the output (A=B) of the magnitude comparator 74LS85 remains low. When the counter reaches the keyed energy level in the register, then (A=B) output goes high. This change of state actuates the relay that triggers the load off the supply [5]. If down-up counters were used, this construction would have been less complex as simple as a clock work piece. There would have been no need for registers or memory devices.

3.0 Design procedure

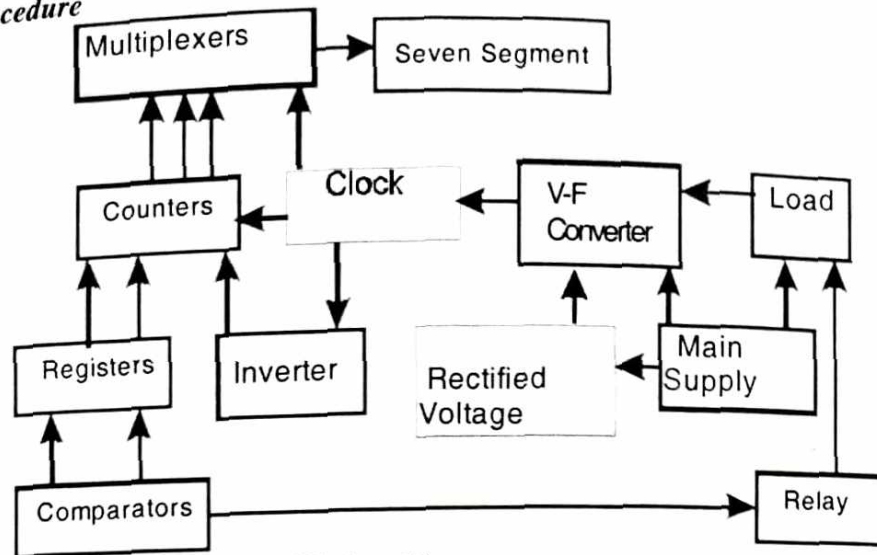


Fig. 2.0 Schematic representation of a Kitchen Timer

The two components that will ensure accuracy of operation of the digital kitchen timer are the current and voltage transformers. To choose the appropriate transformers, an estimate of power consumption of the major components used in the construction has to be known as presented in the table below.

Table 1. Power consumption of components [6]

S/N	Component	Qty	Unit power Consumption, mW	Power Consumption, mW
1.	74LS48	6	35	210
2.	74LS192	8	30	240
3.	74LS90	2	20	40
4.	74LS08	1	10	10
5.	74LS157	4	10	40
6.	74LS196	2	25	50
7.	74LS85	2	15	30
8.	74LS7805	1	5	5
9.	LM324	2	25	50
10.	NE555	4	50	200
11.	SRD-6VDC-SC	1	336	336
	+40% additional losses	--	--	484.4
Total power consumption =				1625mW

1. Choice of current transformer [7]

(a) System voltage $V_{sys} \geq V_{1, rated} = 220$ volts
Maximum current of transformer (secondary side)

$$I_{2max} = P/V_2 \cos \phi = 1.625/12 * 0.8 = 0.169A$$

Load current on the primary turns of voltage transformer

$$I_{1max} = P/\sqrt{3} * V * \cos \phi = 25 * 10^3 / \sqrt{3} * 220 * 0.8 = 82A$$

(b) Maximum current $I_1 \leq I_{1, rated}$, so the rated current of the primary turns of the current transformer is taken to be 100A.

The load resistance of the secondary turns of the transformer is

$$r_2 = P/I_{2max}^2 * \cos \phi = 1.625/0.169^2 * 0.8 = 71.12 \text{ ohms}$$

The turns ratio of the secondary winding of the current transformer at $N_1 = 1$ turn.

$I_{2max}/I_1 = N_1/N_2$, $N_2 = N_1 * I_1/I_{2max} = 1 * 82/0.169 = 485$ turns. For the primary turns with 82A, a single strand of copper wire of current density of $100A/mm^2$ can be used.

The resistance of the primary winding is $r_1 = r_2/k^2 = 71.12/485^2 = 0.0003 \text{ ohm}$.

where k = coefficient of transformation of the current transformer. The cross-sectional area of the conductor

$$a_1 = \rho I_{cal} / r_1 = 0.0172 * 0.2 / 0.0003 = 11.47 mm^2$$

take $I_{cal} = 0.2m$ for one phase TA,
A wire of diameter $d = 3.82mm$ will be used.

2. Secondary turns of current transformer

$r_2 = 71.12$, $I_2 = 0.169A$, a copper wire of current density $1.0A/mm^2$ will be used.

$$\text{Radius of wire used: } R_{22} = \sqrt{(I_2/J * \pi)} = \sqrt{(0.169/1.0 * \pi)} = 0.232mm$$

The length of wire used in the secondary side of the current transformer is defined thus:

$$a_2 = \rho l_2 / R_{22} = 0.0172 * 0.699 / 0.232 = 0.052 \text{ mm}^2, \text{ or } d_2 = 0.464 \text{ mm, where } l_2 = \pi r_2 R_{22}^2 / \rho = \pi * 71.12 * 0.232^2 / 0.0172 = 0.699 \text{ m}$$

3. Choice of voltage transformer

$V_1 = 220 \text{ Volts}$, $V_2 = 12 \text{ Volts}$, $I_1 = 82 \text{ A}$, $P = 1.625 \text{ watts}$.

The current density of the wire used for the secondary winding is 1.0 A/mm^2 , same as the secondary side of the current transformer. The current at the primary side of the voltage transformer is:

$$I_1 = S/V = 1.625 / (0.8 * 220) = 0.01 \text{ A}$$

$$r_1 = r_2 / (1/k^2) = 71 * 18.33^2 = 23855.2 \text{ ohm}$$

Radius of wire $R_{11} = \sqrt{(I_1 / \pi * J)} = \sqrt{(0.01 / \pi * 1)} = 0.056 \text{ mm}$ or $D_2 = 0.11 \text{ mm}$. The length of wire for the primary winding of the voltage

transformer: $l_1 = \pi r_1 R_{11}^2 / \rho = \pi * 23855.2 * 0.056^2 / 0.0172 = 13664 \text{ mm}$ or 13.7 m .

Voltage per turn of the primary winding is $V_t = V_1 / N_1 = 220 / 550 = 0.4 \text{ volt}$, the primary winding is arbitrarily taken to be 550 turns.

For the secondary side of the voltage transformer: $I_2 = P / V_2 * \cos \phi = 1.625 / 12 * 0.8 = 0.169 \text{ A}$.

$$R_{21} = \sqrt{(I_2 / \pi * J)} = \sqrt{(0.169 / \pi * 0.50)} = 0.328 \text{ mm}$$

$$r_2 = V_2 / I_2 = 12 / 0.169 = 71 \text{ ohms}$$

The length of the secondary winding wire for the voltage transformer will be defined through the cross-sectional area of the secondary winding conductor:

$$a_2 = \rho l_2 / r_2 \text{ and } a_2 = \pi R_{21}^2, \text{ therefore } \rho l_2 / r_2 = \pi R_{21}^2, \text{ making } l_2 \text{ the subject formula, we have:}$$

$$\pi r_2 R_{21}^2 / \rho = l_2 = \pi * 71 * 0.328^2 / 0.0172 = 1395.2 \text{ mm or } 1.4 \text{ m.}$$

The number of turns of the secondary winding is calculated with the ratio; $V_2 / V_1 = N_2 / N_1 = N_2 = N_1 V_2 / V_1 = 550 * 12 / 220 = 30 \text{ turns}$, where the voltage per turn is: $V_t = V_2 / N_2 = 12 / 30 = 0.40 \text{ volts}$, where $r_2 =$ resistance of secondary winding of transformer and $R_{21} =$ radius of wire used. The calculated values of these current and voltage transformers for the ADCs are shown in table 2.

Table 2 Sizes of conductors for the Current and Voltage transformers

Type of Transformer	Type of winding	No. of turns	Diameter, Mm	Current A	Length, of wire, m	resistance ohm(s)
Current Transformer	Primary	1.0	3.82	82	0.20	0.0003
	Secondary	485	0.464	0.169	0.699	71.12
Voltage Transformer	Primary	550	0.11	0.01	13.7	23855.2
	Secondary	30	0.656	0.169	1.40	71.0

4. The NE555 Timer

The frequency of the timer is calculated as:

$$F = 1.44 / (R_1 + 2R_2) * C_1 = 1 \text{ Hertz}$$

The resistance that will give 1Hz frequency is between $100 \text{ K}\Omega$ and $1 \text{ M}\Omega$

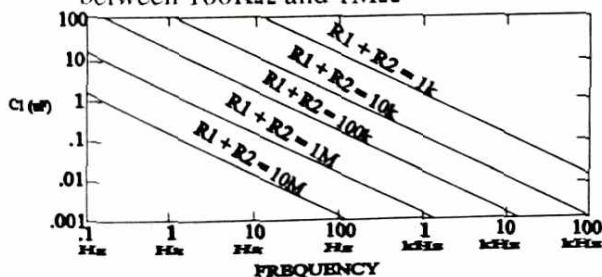


Fig. 3.0 Graph of frequency versus capacitance [8]

4.0 Conclusion

The circuit could have been simplified using a voltage- controlled-oscillator, NE556 and voltage-to-frequency converter TS9400

We can choose any value between these two numbers. If we choose $150 \text{ K}\Omega$, then $R_1 + R_2 = 150 \text{ K}\Omega$, therefore either R_1 or R_2 has a maximum value of $1 \text{ K}\Omega$. If $R_1 = 1 \text{ K}\Omega$, then $R_2 = 74.5 \text{ K}\Omega$ and $C_1 = 10 \mu\text{f}$.

The resistance of the limiting resistor of the seven segment display can be calculated as: $R = (V_{cc} - V_f) / I = (5 - 2) / 0.007 = 428.6 \Omega$, where V_f - forward voltage drop of the 74LS48 decoder. Efficiency of the kitchen timer depends on the normally closed relay which must always react to the operational regime of the device.

integrated circuits. This is a major achievement in the construction of a voltage, current and frequency dependent digital kitchen timers. The use of the clock is to enable the gate to produce an output only when a load is connected. This

device can do more in terms of safety guaranty and free fire hazards as it can switch off an entire household in the event of failure to switch off manually. At short circuit in the house, the clock runs faster and quickly cuts off the load.

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