DESIGN AND IMPLEMENTATION OF MICROCONTROLLER BASED LOAD MONITORING AND INTELLIGENT POWER FACTOR CORRECTION DEVICE

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ABSTRACT

The presence of reactive elements in electrical or electronics appliances results in reactive power, leading to less than unity power factor which is undesirable. Power factor correction (PFC) is a technique for counteracting the undesirable effects of electric loads that create a power factor that is less than one. A PFC of electric circuit using an Atmega 328P Microcontroller was presented. A load monitoring circuit comprising of voltage and current sensing circuit together with a zero crossing detector circuit was designed. An intelligently varying capacitor switching circuit was used to correct the instantaneous load variations in the circuit. A hardware implementation of the circuit was successfully implimented with a rapid response time and on-demand correction capacitive value and switching. This work could be extended to studying a sustainable and cost efficient power systems for smart homes and smart cities as well as any system requiring continuous energy utilization for achieving energy cost reduction.

Keywords: energy, power factor correction, zero cross detection (ZCD), Voltage sensing circuit, microcontroller

1 INTRODUCTION

With constant increase in demand for energy, which occasioned increase cost of energy/ power supply, it has imperative to remove undesirable and wastages in power consumption, hence, the need to adopt power factor correction (PFC) as a means of consumed energy/power cost reduction. Power factor is the ratio of the real power to the apparent power consumed by the load. Most industrial loads exhibit overrall inducitive load characteristics, and have low power factor not transcending 0.8 and thus imparts to the distribution losses, as such, various methods of PFC have been proposed [1]. One of the impendent is to use a fixed capacitor as a source of reactive power for compensating local reactive power demand [2, 3[provided the load is of inductive in nature. This approach is more reliable because it implies the count of lagging current in the power factor with very precise step setting in term of calculating the phase angle in power factor correction schemes [4]. A more elaborate laboratory model of a microcomputer-based power factor controller for compensating the reactive power of rapidly varying loads by switching capacitors sized in a binary ratio was reported by [5] with the help of zero voltage static switches. Four types of control strategies were tried, viz., (1) unity step control method, (2) binary search method, (3) successive approximation method, and (4) look-up table method. Features like (a) independent control of current in each phase, (b) reactive current sensing and capacitor switching in one cycle, (c) zero voltage

switching of static switches to prevent the occurrence of transients and harmonics, and (d) switch failure detection logic and their display, are all incorporated in the software programming. [6] proposed an improved method of programming of Programmable Interface Microcontroller (PIC) for PFC that described the design and development of a three-phase power factor corrector using the PIC chip. This involved sensing and measuring the power factor value from the load using PIC and sensors, then using proper algorithm to determine and trigger sufficient switching capacitors in order to compensate excessive reactive components, thus pushing power factor near to unity. In order to improve the power factor, one method is using static capacitors to either switch on or off based on the power factor value [7]. However, the paper could not present a variable capacitor for varying power factor values as well as the full hardware schematic design used and the output results. Moreover, an improved version of the static capacitors switching method was designed successully nevertheless as a form of a prototype with fixed resistive and inductive loads by [8]. [9] presented a Microcontroller based PFC using PIC Microcontroller. He presented an efficient method to monitor the load and calculate the required capacitance to correct the power factor. In addition, [9] describes development of single phase Silicon Controlled Rectifier based Static Volt-Ampere Reactive Compensate (SVC) for reactive power compensation and power factor correction using Advanced RISC Machines (ARM) microcontroller. The backlash of the project was a lack of determined capacitor value to counteract the undesirable effect of the power factor shift [10]. [11] designed an auto-adjustable power factor correction to ensure the entire power system always preserves unity power factor using a AT89S52 microcontroller. They used a capacitor bank to correct low Power factor. The implementation was only on simulation with a low impact on real circuit implementation. In the work of [12]. PFC using Arduino Microcontroller with the use of a Zero crossing detector circuit to detect the phase difference between the voltage and the current circuit was presented. The paper could only present the circuit and the effect of using the zero cross detector circuit without further impact on a real electrcial circuit. [13] reviewed the vaious industrial methods of PFC and their disadvantages. They also presented a better alternative with the use of 8051 Microcontroller based PFC. The downside of their circuit is the lack of voltage and current detector circuit to determine the exact power consumed in the circuit and also the required capacitor value to correct the power factor. This works reviewed above described researches done in the area of power factor improvement of inductive load. This paper presents a hardware design and implementation circuit consisting of a voltage and current sensing circuit. In addition, a zero crossing detector circuit was used to determine the instantaneous Power factor of the circuit. Moreover, a better algorithm for automatic detection and controlling of Power Factor for an inductive load was used.

2 METHODOLOGY

As shown in figure 1, the overall system requires a Microcontroller, the programme for intelligent control, some electronic components, transformers, and bank of varying capacitors for the implementation the design.

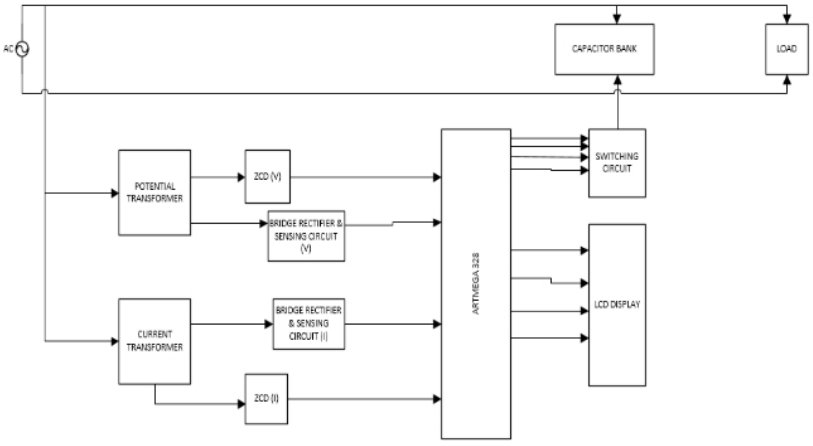

Figure 1. Power factor corrector (PFC) circuit block diagram

The current and voltage signal are acquired from the main AC line (L) by using Current Transformer and Potential Transformer. These acquired signals are then pass on to the zero crossing detector IC (ZCD I & ZCD V) individually that transposed both current and voltage waveforms to square-wave to make perceivable to the microcontroller to observe the zero crossing of current and voltage at the same time instant. Specially designed sensor circuits for both current and voltage signals transpose the analogue signal to the digital signal. Microcontroller read the RMS value for voltage and current used in its algorithm to intelligently select the value of in-demand capacitor for the load to correct the power factor and monitors the behaviour of the enduring load on the basis of current depleted by the load. Synchronizing circuit is developed to synchronize the zero cross detection circuit, Microcontroller and LCD with incoming supply voltage. In case of low power factor, Microcontroller send out the signal to switching unit (relay) that will switch on the in-demand value of capacitor. The tasks executed by the Microcontroller for correcting the low power factor by selecting the in-demand value of capacitor and load monitoring are displayed on Liquid Crystal Display (LCD). The flow chart of the whole process is shown in Figure 2.

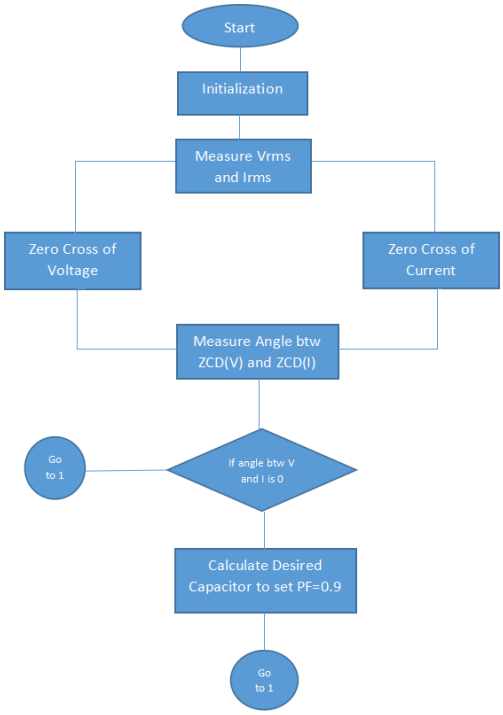

Figure 2. Program flow chart

The flow chart of the proposed intelligent power factor controlling and load monitoring is shown. In the flow chart, the first step is initializing the ACPF circuit. Microcontroller measures the line voltage (Vrms) and line current (Irms) through ADC pins (AN0 and AN1) on real time basis. The voltage and current signals which have been converted into square waves after zero crossing are provided to Microcontroller input pins (RC1 and RC2) that are fundamentally the input of capture module of the Microcontroller. If the zero crossing of voltage and current signals acquired by the Microcontroller points out that V and I signals are not in phase and power factor of load is less then set referenced value of 0.9 lagging then Microcontroller instructs switching action to involve the required value of capacitor to counterbalance the power factor by running values acquired from the load through the algorithm/programme written onto the Microcontroller against the reference value set in the algorithm. Microcontroller does not execute any action if both the voltage and current square-waves provided to capture module of the Microcontroller's pin are in phase or the measured power factor is 0.9 set as referenced value to allow for a magnetizing current value. The LCD displayed the measured values of low power factor, corrected power factor, and the value of capacitor used to correct the low power factor.

3 DESIGN

Various design stages were adopted, the initial stage was performing the mathematical modelling of the problem. The mathematical functions were transformed to circuit design based on the required output as a result of the input. The next design stage was the simulation stage. The simulation was carried on a Proteus Professional CAD software Version 8.4. After the simulation stage, the circuit was executed on a bread board and then soldered on a PCB board. The Sensing circuit in figure 3 is used to sense the analog values of the circuit and converts it to a scaled down voltage suitable to be read by the Microcontroller. The biasing resistors scale down the average output voltage to a value that could be read by the microcontroller. The potentiometer serves as a voltage divider to the microcontroller, it scales down or increases the voltage based on the resistance of the potentiometer.

3.1 Voltage and Current Sensing Circuit

Figure 3 shows the voltage and current sensing circuit design.

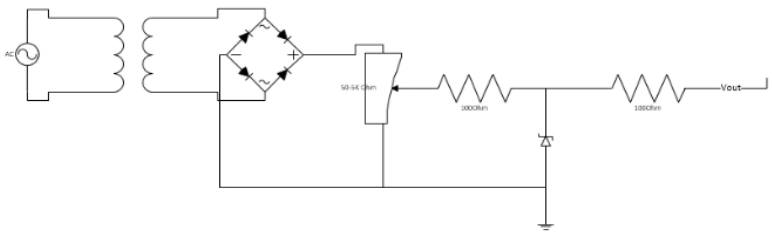

Figure 3. voltage and current sensing circuit design

3.2 Mathematical Formulations for Determining the Correction Capacitor Value

V_{rms} and I_{rms} are read by the Microcontroller using ADC ports. The square-wave voltage and current signals are passed across the voltage and current transformer to achieve zero crossing which is then provided to the Microcontroller that determines which of the signals is leading or lagging. Power Factor is then measured by the Microcontroller using the leading or lagging information together with the power factor formulation shown in table 1 earlier embedded into the Microcontroller via the programme/algorithm.

Table 1. Power Factor Formulation

Description	Formula	Explanation
Real Power	$P = I_{RMS}V_{RMS}\cos\theta$	$\cos\theta$ is the power factor
Phase Angle	$\theta = 360 * f * \Delta T$	Δ_T is the time difference between ZCD(V) and ZDC(I) and f is the supply frequency
Power Factor	$PF = \cos\theta$	For angle detection by taking the cos inverse of cos theta (θ) and getting the angle theta (θ)
Reactive Power	$VAR_1 = P * \tan\theta_1$	
Reference Reactive Power	$VAR_2 = P * \tan\theta_2$	Set the theta (θ) as a reference value equal to 0.9
Required Reactive Power	$VAR = VAR_1 - VAR_2$	
Required Impedance of X_C	$X_C = \frac{V_{RMS}^2}{VAR}$	
Required Capacitance	$C = \frac{1}{2\pi f Xc}$	

3.3 Zero Crossing Detector Circuit

In figure 4, a voltage and current zero crossing detector (ZCD) was used. Both Zero crossing circuits consists of a step-down transformer that steps down the incoming high voltage and current to a suitable value. In addition, a Voltage divider circuit and a comparator circuit was used. It also consists of an op-amp comparator circuit. The comparator consists of a non-inverting reference input that compares the reference voltage connected to the inverting input of the operational amplifier with the input signal connected to the non-inverting input. When V_{IN} is greater than V_{REF}, the op-amp comparators output will saturate towards the positive supply rail, Vcc. When V_{IN} is less than V_{REF} the op-amp comparators output will change state and saturate at the negative supply rail.

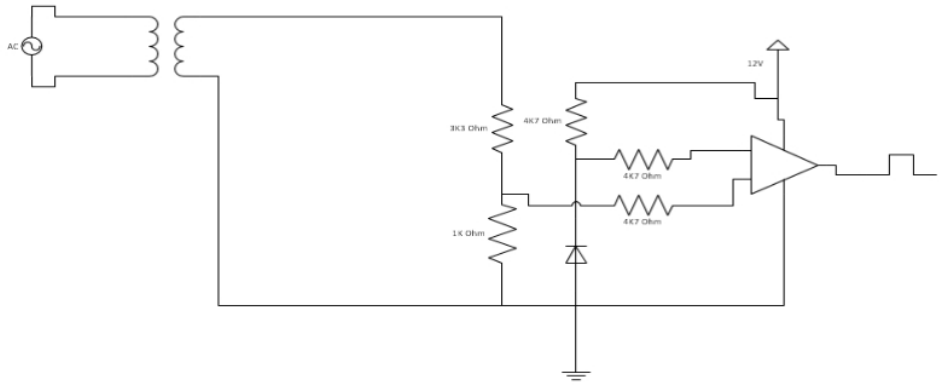

Figure 4. Zero crossing detector (ZCD) circuit

Figure 5 describes the combination of all the circuitry and the arrangement of the electronic components needed to implement the PFC. At the heart of the circuit is the microcontroller, in the design above that was simulated on the proteus software, an Arduino UNO is used for the simulation. The reason is that the microcontroller used on the Arduino UNO is the Atmega 328P and the performance is the same as using a single Atmega 328P microcontroller.

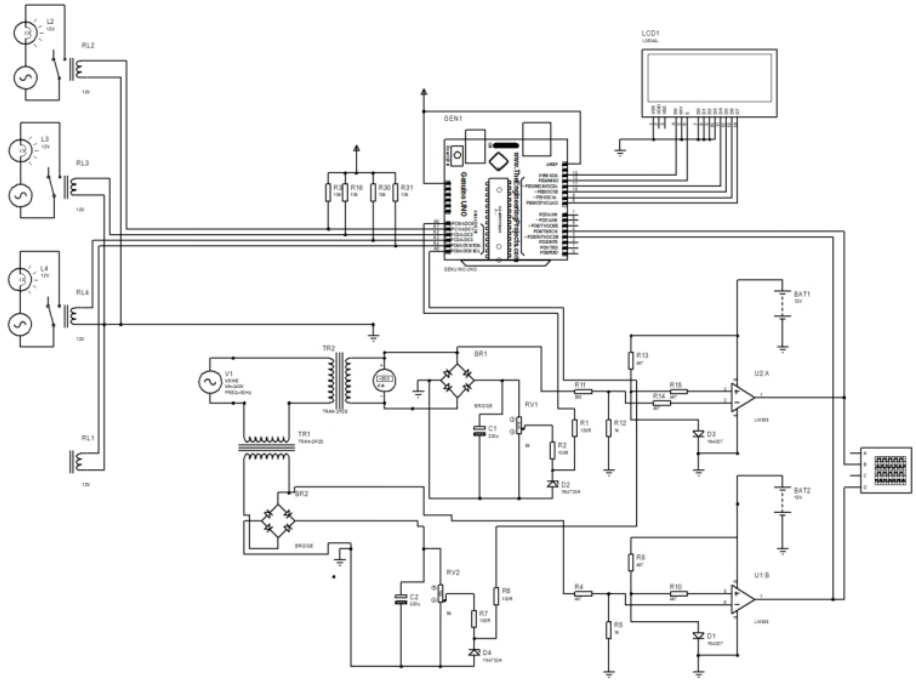

Figure 5. Power factor correction circuit component design

There are four inputs to the Microcontroller, the inputs from the voltage and current sensing circuits are set to the Analog pins A0 and A5 respectively. The digital Pins 3 and 4 are set as the inputs from the current and voltage zero crossing detector circuits as shown in Figure 4. There is a total of eight outputs from the microcontroller, six of the pins are for the LCD and four are for the Relays. LCD Pins are Digital pins, 13, 12, 11, 10, 9, 8 and the Relay pins are the digital pins 15, 16, 17 and 18. This is the arrangement of the pins and the setup of the whole circuit. And Figure 6 describes the layout diagram of the circuit.

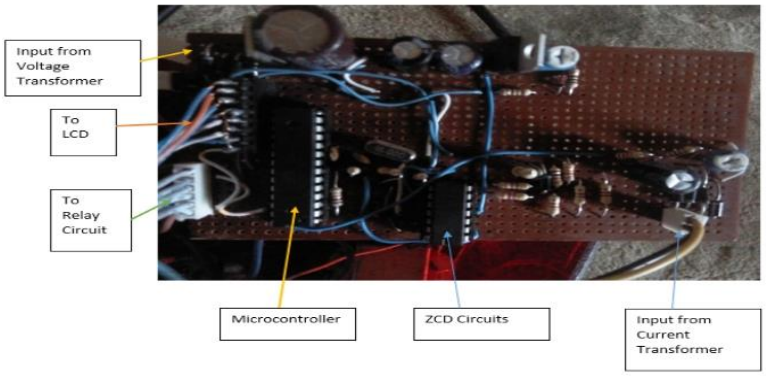

Figure 6. Hardware circuit layout

4.0 SIMULATION RESULTS

After the design process of the circuit and the programming of the microcontroller has been completed, the next phase is to test the circuit design in a simulation software. There are three testing phases used in the simulation. The first stage involves a no load testing of the circuit. The second stage is to use a simple phone charger to test the design. The third stage is to use a phone and a laptop charger.

4.1 No load

Figure 7 describes the no load situation of the Intelligent PFC device. It can be seen from the LCD that the voltage sensed 226.7V and current of 0A. As it can be seen the Power is 0W and the capacitor value needed for the correction is 0 uF. The scope from the diagram shows a fluctuating input from the Voltage ZCD but a flat line for the current ZCD due to the 0A from the current source.

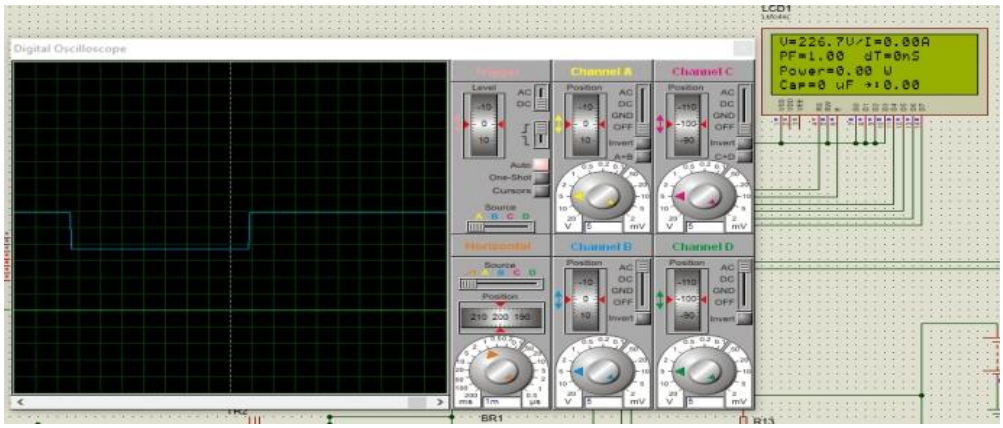

Figure 7. No load simulation result

4.2 Phone Charger Load

In Figure 8, the Voltage is 227.3V and a current of 0.37A thus the average power is 37.98W. The PF has fallen to a value of 0.81 from the 1.00. The required correction capacitor value is displayed as 1uF. The scope displays the time delay between the voltage and the current.

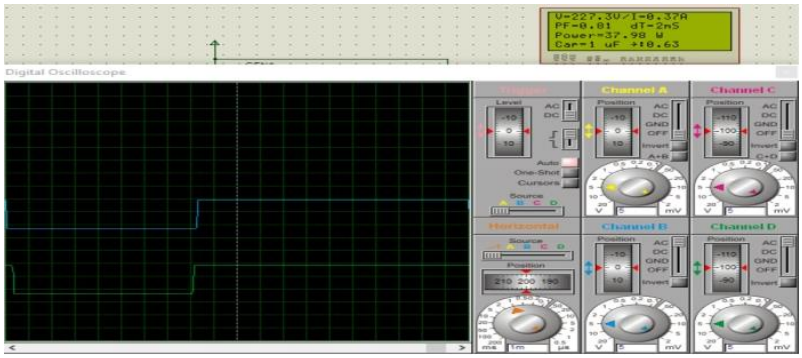

Figure 8. Phone charger simulation result

4.3 Phone and Laptop charger

In Figure 9 the LCD display shows a voltage is 227.9v and the current 0.69A. The power displayed is 71.14W with a power factor of 0.95 and a correctional capacitor of 100μF. The high-power factor could be attributed to the fact that most laptop chargers are of high-power factor rating sometimes at unity PF.

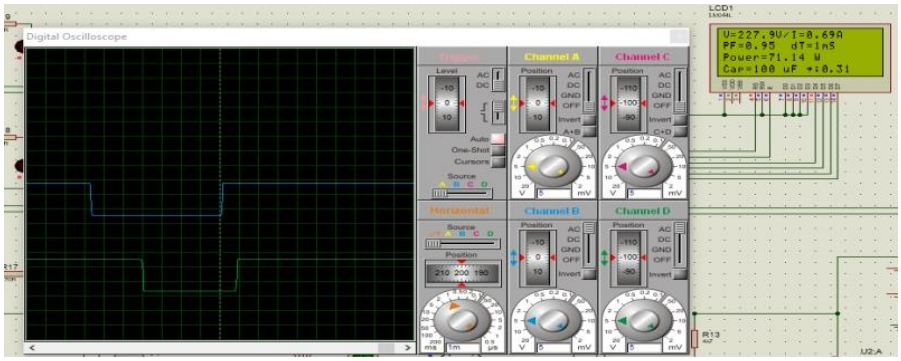

Figure 9. Phone and laptop charger simulation result

5 DISCUSSION OF RESULT

This work is to design and implement the intelligent PFC controlling system using Atmega Microcontroller (328PI). The Microcontroller senses the power factor by continuously monitoring the load on the system, and being mostly inductive, the circuit behaviour is characterized by lagging current thereby exhibiting low PF due to load the load. The circuit intelligently performs the control action through a proper algorithm by switching capacitor bank through different relays to improves the power factor of the load. This work gives more reliable and user-friendly power factor controlling system by continuously monitoring the load of the system. Measuring of power factor from load is achieved by using Atmega Microcontroller and the written algorithm to determine and trigger sufficient switching of capacitors in order to compensate demand of excessive reactive power, thus bringing power factor near to desired level. And the results obtained are discussed below and shown in Table 2.

Table 2. Hardware Comparison Result

LOAD	CURRENT DRAWN	Initial PF	Corrected PF	Required Capacitor
No Load	0.00A	1.00	-N/A	0uF
Laptop Charger	0.87A	0.85	0.95-1.00	10uF
Laptop + Phone Charger	0.93A	0.79	0.95-1.00	11uF
Laptop +Phone Charger +Fan	1.03A	0.54	0.95-1.00	100uF

In performing the experiment on the actual circuit, certain parameters were used to qualitatively measure the impact of the power factor correction on the actual circuit. The first parameter is to measure the current drawn in the circuit according to the load applied to the circuit. The next stage of the experiment

is to determine the power factor of each load and the required capacitor necessary to correct the power factor.

6 CONCLUSIONS

This work demonstrates an efficient technique to improve the power factor of power systems in an economical, efficient, and intelligent manner. Static capacitors are invariably used for power factor improvement in factories or distribution line. But this paper presents a system that uses capacitors only when power factor is low otherwise, they are cut off from line. Thus, it not only improves the power factor but also increases the life time of static capacitors. The power factor of any distribution line can also be improved easily by low cost small rating capacitor. This system with static capacitor can improve the power factor of any distribution line from load side. However, should a static capacitor be applied in high voltage transmission line, then its rating will be unexpectedly large and will be uneconomical and inefficient. This accounts for the use of variable speed synchronous condenser in high voltage transmission line to improve power factor, with the speed of synchronous condenser controlled by microcontroller or any controlled device.

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