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DEVELOPMENT OF MEASURING AND COMPUTER INTERFACE SYSTEM FOR AN INDUSTRIAL ELECTROSTATIC PRECIPITATOR

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Abstract

The paper describes the design and practical implementation of a measuring and digital computer interface system for an electrostatic precipitator (ESP) used in a large cement factory. The objective is to develop a digital computer control system to replace an old analog controller for the ESP filter mounted on a cement production rotary kiln inside the National Cement Company. The main concern is to develop a modern technology for a real ESP controller designed and implemented locally in Egypt. The first phase of this research project is described in this paper.

The computer interface system is developed to facilitate measurements of voltages and currents at both low voltage and high voltage sides of the transformer/rectifier power circuit of the high voltage unit in the EPS. Hardware, software, electronic circuits and interface systems are described. Practical results of the real precipitator are presented to show the validity of the designed system.

1. INTRODUCTION

Electrostatic precipitators are widely employed in various industries and premises to clean air and waste gasses by removing suspended particles using electrostatic forces [1]-[3]. They have found many applications in cement production plants and power boilers, and also in cleaning indoor air in special buildings such as hospitals and food processing factories. Some of the industrial applications of electrostatic precipitators are listed in the following table.

To operate at high efficiency and low cost, the electrostatic precipitator (ESP) should be tightly and accurately controlled and monitored [4]-[6]. Several controlled high voltage units are normally used in the ESP. These units provide the high voltage required for the precipitator electrodes to generate the electrostatic field through which the gasses to be cleaned are passed.

Table 1: Industrial Applications of Electrostatic Precipitators

Industry	Applications
Thermal power stations	Remove dust from exhaust gases of boilers
Coal	Dust precipitation in steam and gas-heated coal dryers
Chemicals and fertilizers	Demisting of gases
Industrial air-conditioned installations	Air cleaning
Paint	Separating metal oxides, pigments
Iron and steel	Remove dust from waste gases of blast furnaces

One of the most important and advanced computer applications in industry is to use digital computers to control and monitor operation of electrostatic precipitators [4], [5]. Other emerging application of digital computers in the electrostatic precipitation field is numerical computations of complex characteristics [7], [8].

The objective of this paper is to design, implement and practically test a measurement and computer interface system for a high voltage unit supplying a precipitator in a large cement kiln. The measured variables are voltages and currents at both low voltage and high voltage sides of the transformer/rectifier power circuit supplying the precipitator filter. The measured signals are interfaced with the computer through a data acquisition card. The measured data are processed and can be monitored on the computer screen on steady-state and transient conditions. The measured variables can be recorded and stored for further analyses. A triggering circuit has been also designed and implemented to provide the control signals to the thyristors used in the power circuit of the precipitator filter. Field test results of the real electrostatic precipitator filter are presented to show the validity of the measuring and interface system.

2. ELECTROSTATIC PRECIPITATOR

In many industries such as cement industry, huge amounts of small dust particles are released in the open air, thus causing environmental pollution. The electrostatic precipitator is a filter used in industry for separation of dusts from dust-loaded flowing gases to prevent emission of these dusts to surrounding environment.

The ESP utilizes electrostatic forces to separate dust particles from the gas to be cleaned. The ESP comprises a number of discharge electrodes which hang vertically between grounded parallel plates called collecting electrodes as shown in figure (1). The separation between two successive collecting electrodes is usually 20 to 25 cm [3]. A high negative voltage is applied to the discharge electrode system. Ionization or corona discharge occurs near the surface of the discharge electrodes and large quantities of positive and negative ions are formed. The positive ions are immediately attracted towards the negative electrodes by the strength of the electric field. As the dust particles enter the precipitator, they are charged negatively by the mobile negative ions which then interact with the electrostatic field producing a force which causes them to migrate to the grounded plate where they are collected. The dust layer is removed by rapping the plates, causing the dust to fall into hoppers located below the plates. These particles are then carried outside the ESP [1].

To realize the effectiveness of the electrostatic precipitators in preventing air pollution, figures (2) and (3) are given to show a real cement factory before and after properly operating the electrostatic precipitators, respectively. The surrounding environment is clearly improved with the electrostatic precipitators.

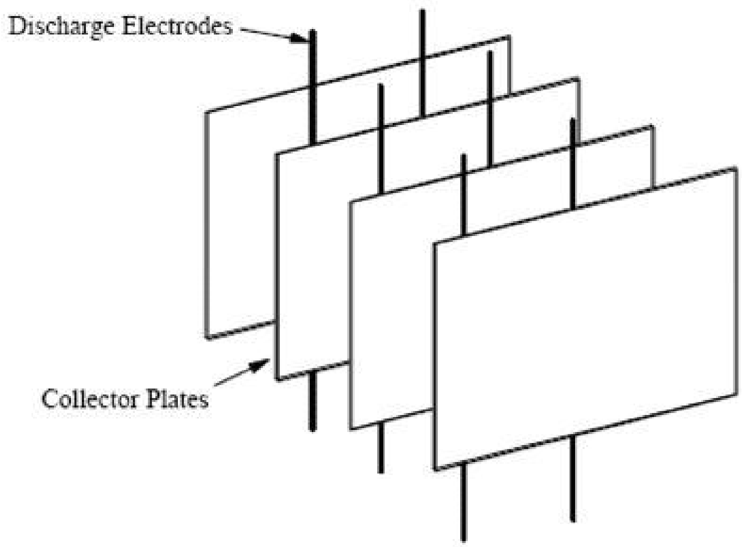

Figure (1): Schematic of ESP electrode system

Figure (2): Photograph of a cement factory without operating ESPs.

Figure (3): The same factory of figure (2) after ESPs operation.

3. SYSTEM DESCRIPTION

The electrostatic precipitator of concern is a filter mounted on a cement production rotary kiln inside the National Cement Company, El-Tebbin, Cairo, Egypt. Figure (4) shows this ESP. The filter consists of two parallel precipitators of type YI 2-4-74; each has 4 fields. Thus, the total fields of the ESP are 8. The waste gas flow capacity is 236047 m^3/hour, and the active cross-section area is 74 m^2. The ESP is equipped with 2 fans; each has a 500 kW, 6 kV, 3 ph. motor.

Each field in the ESP is equipped with a high voltage unit located in a power distribution station beneath the filter. The HV unit consists of a transformer, rectifier bridge, HV connector, and control device. Experiments were made upon the HV unit that supplies the ESP field 8:

Rated mains = 380 V, 50 Hz, 248 A.
Rated output = 50 kV (mean), 80 kV (peak)
Rated rectified load current = 1000 mA (mean value)

Additional details of the ESP and HV unit specifications can be found in [9].

Figure (4): The ESP in the National Cement Company.

4. MEASURING SYSTEM

A measuring module is designed and implemented to process four analog signals. The measured signals are the primary winding voltage, the primary winding current, the secondary rectified voltage and the secondary current that flows through the electrostatic precipitator's field.

Figure (5) shows the power and measuring circuits. Each sub circuit is explained below.

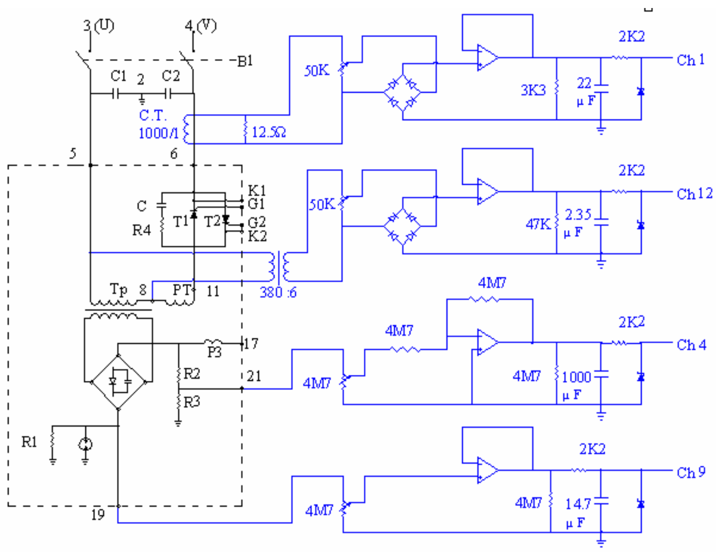

Figure (5): Power and measuring circuit of the high voltage unit.

3.1 Measuring Primary Voltage

The voltage of the primary winding of the transformer is measured through a 380/6 voltage transformer connected across the primary voltage winding terminal. The output of the transformer is connected to two terminals of a 50 KΩ potentiometer whose output is adjusted so that the circuit supplies (0-3 VDC) expressing (0-380VAC). A bridge rectifier is placed at the output of the potentiometer. The output of the bridge is input to a buffer circuit to remove any loading-effect on the measured signal. The output of the buffer is then smoothed using a suitable filter consisting of a capacitor and a resistor to give the desired DC signal. A 7 volt Zener diode is connected to the DC signal to protect it against any disturbance.

3.2 Measuring Primary Current

The current of the primary winding of the transformer is measured using a current transformer (C.T. 1000/1 A). The output current of the C.T. is transformed into a voltage difference. The output is adjusted so that the circuit supplies a signal level of 0-3 VDC expressing 0 to 248 A AC. The primary current signal is buffered and filtered. A 7 volts Zener diode is connected to the output of the measuring circuit.

3.3 Measuring Secondary Voltage

The voltage of the secondary winding of the transformer is rectified in a built-in bridge-rectifier circuit designed for high voltage rectification. A built-in voltage-divider circuit gives output protected by a surge arrestor. The measuring point is connected to a 4.7 MΩ potentiometer whose output is adjusted to supply 0-5 VDC expressing 0-50 kV DC. Because the secondary voltage signal is negative, an inverting amplifier is placed at the output of the potentiometer. The output of the amplifier is then smoothed using suitable capacitor and resistor to give the desired DC signal. A Zener diode is also used.

3.4 Measuring the Rectified Secondary Current

The rectified secondary current is allowed to pass through a built-in resistor R1 which is protected using a surge arrestor. The measuring point is connected to a 4.7 MΩ potentiometer whose output is adjusted to supply 0-5 VDC expressing 0-1000 mA DC. The output of the potentiometer is input to a buffer circuit to make no loading-effect on the measuring potentiometer. The output of the amplifier is then smoothed using suitable capacitor and resistor to give the desired DC signal. A Zener diode is connected to the measuring signal output.

5. THYRISTORS GATES TRIGGERING MODULE

A reliable triggering module is built to supply the high voltage unit with the controlling firing signals [10]. The voltage supplied to the primary side of the high voltage unit is taken from two lines of three-phase alternating current supply. The two thyristors T1 and T2 are connected back-to-back in the path of the primary current as shown in figure (5). The firing instants of the thyristors are controlled by adjusting the controlling voltage V_c.

As shown in figure (6), the triggering circuit consists of inverting and non-inverting zero crossing detectors (ZCD) followed by a ramp generator. The firing pulse position is determined by the positive edge of the modulating wave of a voltage comparator. The pulse position is directly proportional to the level of the controlling voltage signal (V_c). The triggering pulses are amplified and isolated through an amplifier and pulse transformer units respectively.

Detailed circuit diagram of the developed triggering circuit is shown in figure (7). Values of the components used for implementing the firing circuit are also shown in the figure.

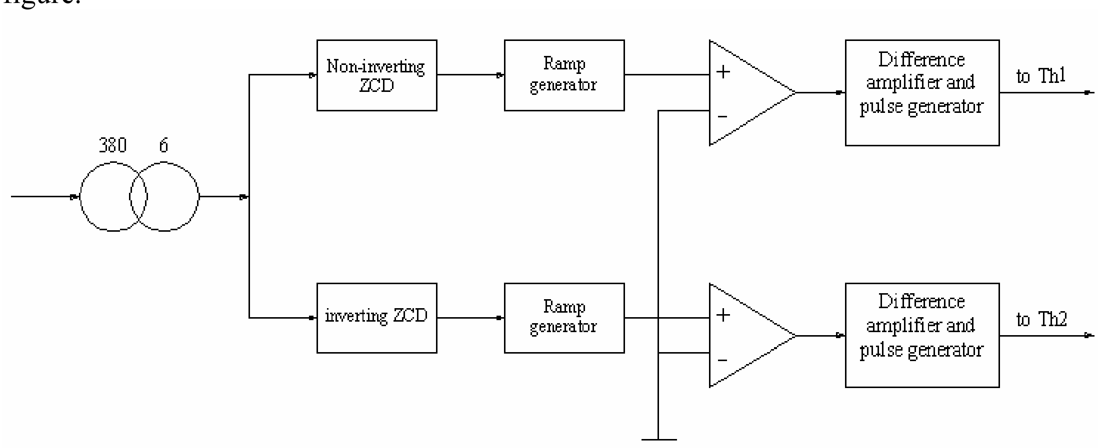

Figure (6): Block diagram of the triggering circuit.

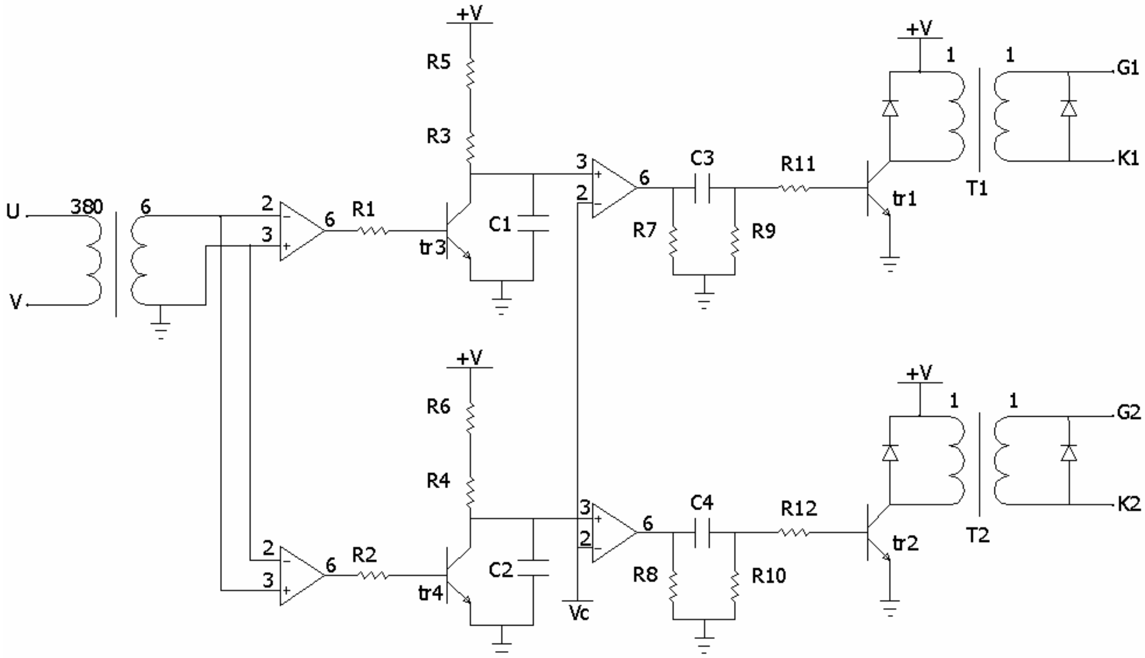

Figure (7): Triggering circuit.

R1 = R2 = 2 kΩ, R3 = R4 = 100 kΩ, R5 = R6 = 47 kΩ pot., R7 = R8 = 10kΩ, R9 = R10 = 15 kΩ,
R11 = R12 = 2 kΩ, C1 = C2 = C3 = C4 = 0.1 μF,
Transistors tr1, tr2, tr3, tr4 are BD137 – npn,
T1 and T2 are pulse transformers

6. INTERFACE MODULE

A digital computer system is developed to operate and control the high voltage unit. The digital system consists of a PENTIUM-3 personal computer with 192 MB RAM and 550 MHz processor. Suitable interfacing module is used to convert the measuring signals of the primary and secondary voltages and currents to the computer. In addition, the controlling voltage is converted from the computer to the triggering circuit to control the firing pulse instants. The interfacing module used works on 12 bit data for A/D and D/A conversion. It has fast conversion speed for both A/D and D/A with suitable accuracy [11]. Block diagram of the developed digital control system is shown in figure (8).

Software routines are written to convert the analog signals to digital values through a digital to analog (A/D) converter. Also, software routines are written for converting the controlling voltage V_c from digital value to analog signal through D/A converter. In addition, the control techniques are converted to software routines in the controlling program. The program routines are written by using VISUAL BASIC compiler to perform these functions. For reading the four inputs (V_1, I_1, V_2, and I_2) and output of the control voltage (V_c), two functions are written. The first function is called “AnalogToDigital” and is used to perform an analog to digital conversion to a channel of the sixteen channels available and then returns the digital count. Adjustments were made for the code to work for VISUAL BASIC and a convenient sampling interval of 4.16 ms was chosen and implemented. The other function is called “convert” and is used to perform an analog to digital conversion to generate the desired control voltage. It also calls the function “AnalogToDigital” four times to read the four channels representing V_1, I_1, V_2, and I_2. The flow charts of the VISUAL BASIC “AnalogToDigital” and “Convert” functions are shown in figures (9) and (10), respectively.

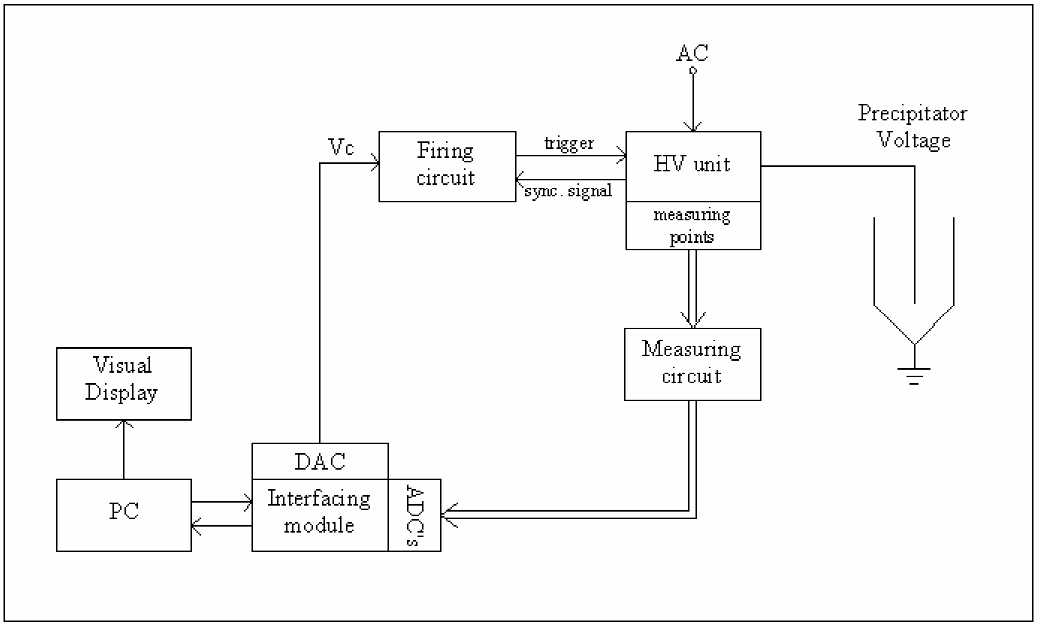

Figure (8): Block diagram of the computer control interface system.

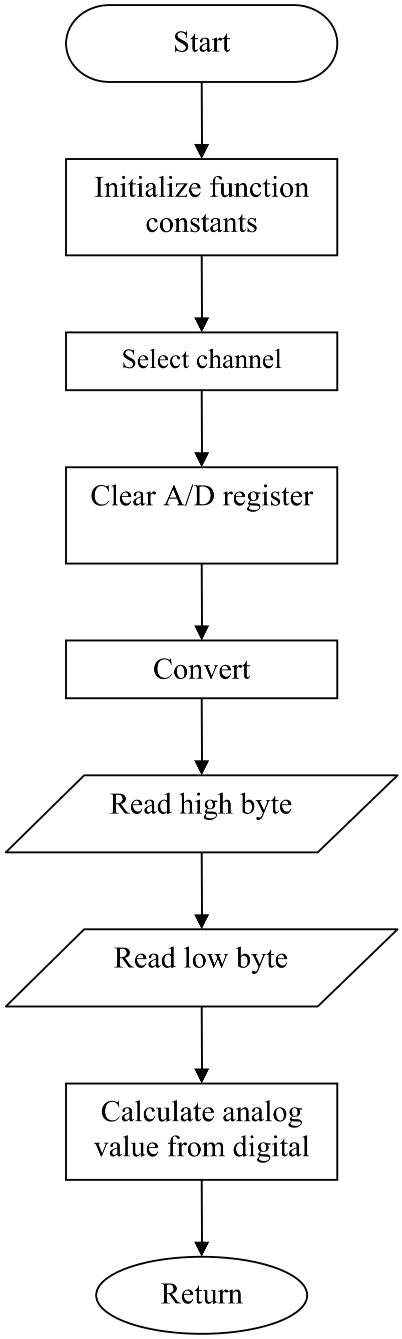

Figure (9): Flow chart of the “AnalogToDigital” function

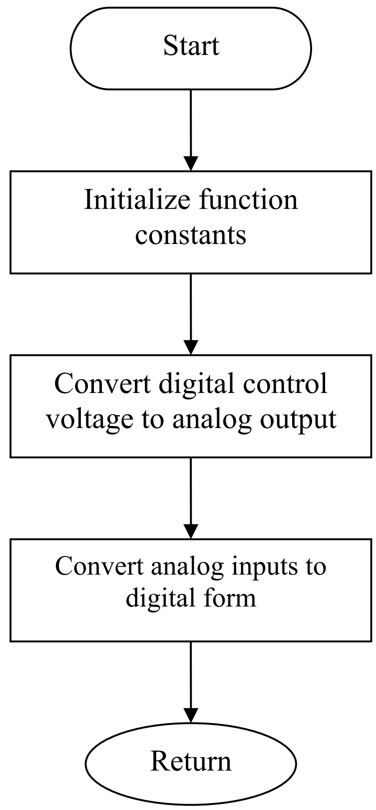

Figure (10): Flow chart on “Convert”

7. PRACTICAL RESULTS

Several testes are performed to evaluate the effectiveness of the developed practical system setup. In each test, the controlling voltage is adjusted to set the firing instants of the thyristors at certain values. The measuring signals are connected to the computer through the interfacing module. Scaling factors of each variable are adjusted practically.

Several values of the controlling voltage (V_c) were output to the firing circuit and the corresponding system variables (i.e. V_1, I_1, V_2, I_2) were recorded. The range of the control voltage V_c is 0 – 9 VDC giving a firing angle of 0 – 180 electrical degrees. Using a controlling voltage of 7 Volts yielded the variables shown in figure (11).

The results indicate that a constant firing angle resulting from a constant controlling voltage gives constant values for the four system variables. Small fluctuations are observed in the displayed responses resulting from uncontrolled parameters such as dust load, moisture, etc. Small overshoots are noticed in the responses when the system is started.

8. CONCLUSIONS

Successful design, implementation and testing of a measuring and computer interface system for the high voltage-unit of an electrostatic precipitator have been presented. The system is shown to perform well in the harsh cement industrial plant. Steady-state and transient values of the measured variables are displayed for continuous monitoring and can be stored for further analyses. The system is capable of implementing closed loop control. The developed measuring and computer interface system facilitates better monitoring and improved operation of the electrostatic precipitator filters in the cement plants, thus improving air cleaning conditions in industrial environments.

9. ACKNOWLEDGEMENTS

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(a)

(b)

(c)

(d)

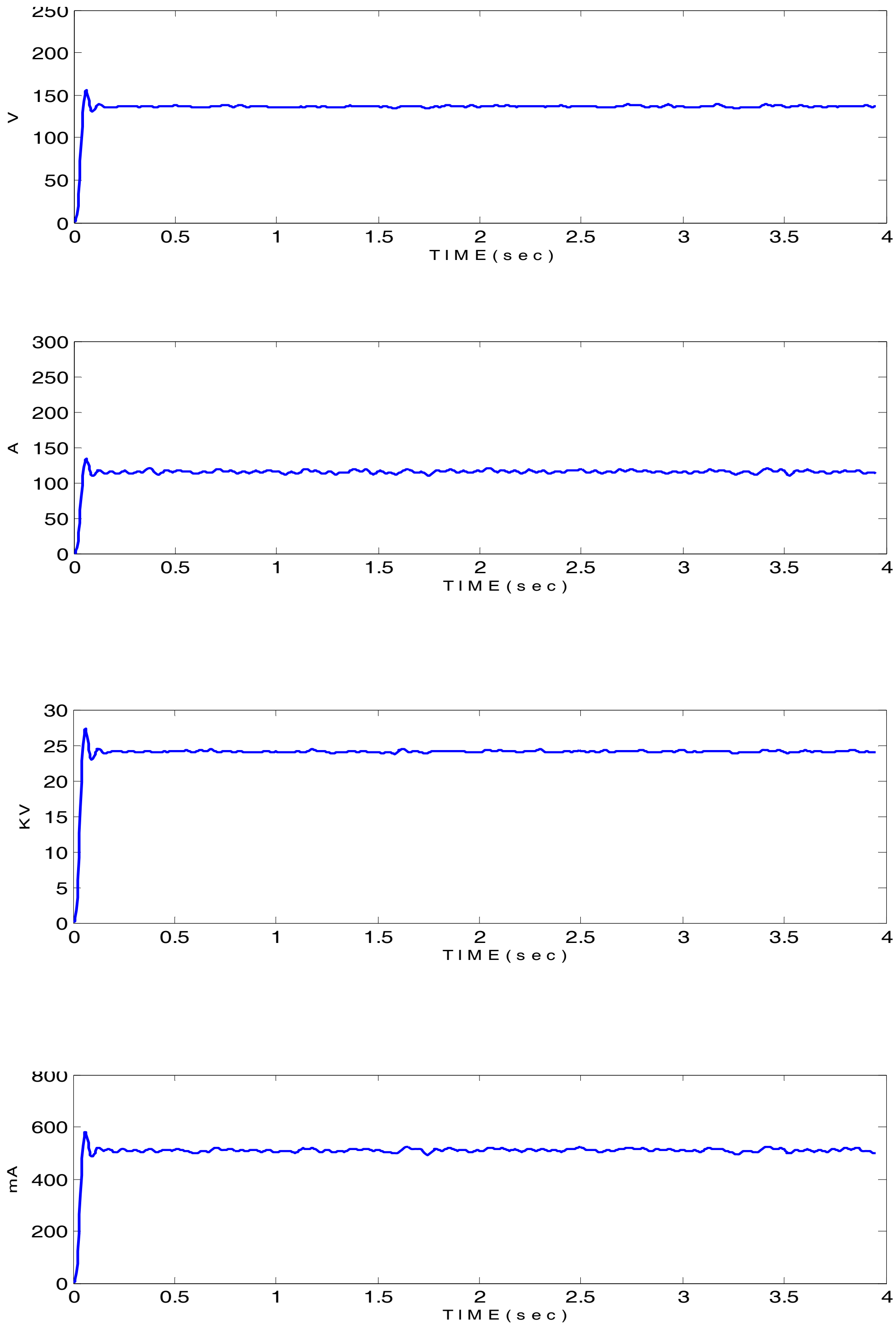

Figure (11): System variables measured for an input of 7 V controlling voltage
(a) V_1, (b) I_1, (c) V_2, and (d) I_2

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