A water and energy conserving irrigation controller

by William Evan Kirkpatrick

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering
Montana State University

Abstract:
Electronic and mechanical irrigation controllers eliminate the task of manually regulating the flow of water. Most controllers water according to a fixed time schedule. These controllers waste water and energy by watering unnecessarily or inefficiently. In market research, no stand alone controller was found capable of modifying both the starting time and duration of watering determined by the major factors affecting water and energy conservation.

Parameters were identified which have the greatest contribution to conserving water and energy. Precipitation amount and level of ground moisture determine the water quantity required and thus the duration to irrigate. High wind speed, high precipitation rate, and low water pressure all make watering less effective or unnecessary. An expandable controller is desirable due to the specific requirements of a particular irrigation system.

An electronic irrigation controller was designed and fabricated to conserve water and energy. The addition of option boards to the basic controller allow for ground moisture, precipitation, wind speed and water pressure measurements. The controller allows for controlling a water pump and up to 24 electric water valves, including a master valve. All programming and control is through a serial communications line, allowing for wired or wireless remote control. The controller uses both a battery backup and nonvolatile memory to be insensitive to power failure.

The use of an intelligent irrigation controller conserves water and energy. Commonly available electronic components allow the controller to be constructed at a relatively low cost. An expandable design and programming flexibility allow adding only the options which will be most advantageous for a particular irrigation system.

A Water and Energy Conserving Irrigation Controller

by

William Evan Kirkpatrick

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Electrical Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 1994

APPROVAL

of a thesis submitted by

William Evan Kirkpatrick

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

July 20, 1994
Date

Chairperson, Graduate Committee

Approved for the Major Department

July 22, 1994
Date

Head, Major Department

Approved for the College of Graduate Studies

7/24/94
Date

Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under the rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature William Evan Hertzsprung

Date 22 July, 1994

ACKNOWLEDGMENTS

This thesis was completed with the help of many people. Harley Leach provided many ideas to improve the functionality of the controller while providing encouragement and expertise. The other members of the thesis committee, Dr. Murari Kejariwal and Dr. Fred Cady, willingly arranged their summer schedules to critique and approve the thesis. Mike McCartney of Aquatech, Inc. helped in obtaining much of the research materials on currently available irrigation products. Tony Braun generously shared his time and expertise. Thank you.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

Electronic and mechanical irrigation controllers eliminate the task of manually regulating the flow of water. Most controllers water according to a fixed time schedule. These controllers waste water and energy by watering unnecessarily or inefficiently. In market research, no stand alone controller was found capable of modifying both the starting time and duration of watering determined by the major factors affecting water and energy conservation.

Parameters were identified which have the greatest contribution to conserving water and energy. Precipitation amount and level of ground moisture determine the water quantity required and thus the duration to irrigate. High wind speed, high precipitation rate, and low water pressure all make watering less effective or unnecessary. An expandable controller is desirable due to the specific requirements of a particular irrigation system.

An electronic irrigation controller was designed and fabricated to conserve water and energy. The addition of option boards to the basic controller allow for ground moisture, precipitation, wind speed and water pressure measurements. The controller allows for controlling a water pump and up to 24 electric water valves, including a master valve. All programming and control is through a serial communications line, allowing for wired or wireless remote control. The controller uses both a battery backup and nonvolatile memory to be insensitive to power failure.

The use of an intelligent irrigation controller conserves water and energy. Commonly available electronic components allow the controller to be constructed at a relatively low cost. An expandable design and programming flexibility allow adding only the options which will be most advantageous for a particular irrigation system.

CHAPTER 1 - INTRODUCTION

Electronic irrigation controllers are popular in industrial and home irrigation systems. The level of controller sophistication varies from simple mechanical timers to complex and expensive personal computer based controllers. The majority of controllers designed for the home market are electronic timers which turn water valves on and off only at user specified times. Their ability to water according to a preset time schedule has two primary advantages:

1. The user need not be present to turn on and off the water.
2. The quantity of water applied by the irrigation system is consistent.

Watering at specific times for fixed periods also has disadvantages. The need for outdoor watering is inherently tied to weather conditions. Wind, rain, temperature and sunlight all affect ground moisture. Watering according to a fixed schedule will inevitability irrigate when either inefficient or unnecessary to do so. This wastes not only water, but in most cases, the energy to supply the water.

Some improvements are available for irrigation controllers to aid in water conservation. Ground moisture and precipitation sensors are available for most controllers.[1,2,3] However, the majority of those sensors completely disable all watering when a discrete level of moisture or precipitation is reached. The most sophisticated irrigation systems use a dedicated PC (Personal Computer) to talk to one or more satellite controllers.[1,2] They are capable of monitoring various weather parameters then modifying the watering of the satellites according to those parameters.

In market research, no stand alone controller was found capable of proportional control of watering dependent on ground moisture, precipitation, wind speed and water pressure.[1,2,3,4,5,6,7,8,9,10,11]

An intelligent irrigation controller was designed to conserve water and energy by monitoring various parameters and proportionally controlling watering based on those parameters. The expandable controller has inputs to measure ground moisture, precipitation, wind speed and water pressure. The user can select the effect those inputs have for each of 24 individual electronic valves.

CHAPTER 2 - THESIS OBJECTIVE

This thesis describes an electronic irrigation controller developed to conserve water and energy while remaining cost competitive for the home market. To meet these goals, commonly available electronic components and existing irrigation products were used where possible. The system was designed as a basic controller onto which options could be added. The terminology used throughout the paper is discussed followed by specific methods to achieve the objective.

Terminology

The following terms are defined as used throughout the thesis:

BLOCK-OUT TIME -

A period of time during which the user does not wish to allow any watering to occur.

DRIP ZONE -

An area watered by low pressure watering devices. Flowers, trees and shrubs are usually watered using drip irrigation. The area watered is relatively small with a low rate of water flow.

ELECTRIC VALVE (or *VALVE*) -

The device used to control the flow of water to the watering devices.

IRRIGATION CONTROLLER (or *CONTROLLER*) -

The mechanical or electronic timing device used to activate the electric valves.

SPRINKLER ZONE -

An area watered by sprinklers. Sprinkler zones are used to water lawns or large areas of landscaping. Water flow rates are generally high.

START TIME -

The time specified when a user wishes to begin either a block-out time or begin watering a group of zones. In the case of watering a group of zones, this time may not be followed exactly, depending on water pressure, rain, wind or a previous block-out time. The watering begins the first minute when conditions allow a valve be turned on.

ZONE GROUP (or *GROUP*) -

A logical ordering of zones for simplifying the control of complex systems. Watering start times are given for each zone group instead of each individual zone.

Controller Parameters

The measurable parameters which affect the conservation of water and energy of an irrigation system were determined.

Ground Moisture

Ground moisture is the most obvious input parameter required to conserve water. The whole objective of irrigation is to change the amount of ground moisture. Soil type, temperature, wind, sunlight and rain all affect the amount of moisture in the ground. Therefore, it is most accurate and economical to measure ground moisture directly, instead of deriving it from the other contributing parameters.

Two types of ground moisture sensors are available:

1. Level switching.
2. Proportional control.

The level switching type of sensor acts independently of the irrigation controller. When a specific level of ground moisture is reached, the controller will be disabled. It is the most common type of ground moisture sensor used because it can be added to an existing controller and is inexpensive. The primary disadvantage of the level switching sensor is the whole system is disabled independent of the intended watering schedule or desired amount of watering.

Proportional control sensors modify the amount of watering dependent on the measure of ground moisture. If low ground moisture is measured, the watering amount will be larger than when the ground moisture is high. The desired amount of water can be more precisely controlled with a proportional sensor. This type of sensor must be integrated with a controller capable of measuring an analog signal then calculating new watering times.

The proportional ground moisture sensor was selected for this project. A sensor output of 0 to 5 V (Volts) was assumed. The signal requires an ADC (Analog to Digital Converter) on the circuit. To use a single sensor for the entire system, the user needs to have the ability to define how sensitive each zone is to the ground moisture measurement. This compensates for differences in evapotranspiration rates from one zone to another.

Precipitation

Measurement of precipitation is used instead of a ground moisture sensor in some systems.[1,2] They disable the entire irrigation system when a certain amount of rainfall is accumulated. The disadvantages are the same as for level switching ground moisture sensors with the additional disadvantages that other parameters which affect ground moisture are not accounted for.

A more effective use of precipitation measurement is during watering. If the precipitation rate exceeds a specified value, watering should be stopped. While raining, the amount of precipitation should be measured. When the rain stops, the watering not yet completed should be reduced by the accumulated precipitation.

A simple precipitation measurement device uses a "teeter-totter". As the device is always tilted to one side or the other, one side fills with water while the other drains. When enough water collects in the high side, the weight of the water causes the device to flop over, filling the side that was previously draining. For the controller, this type of device requires only a single digital input and a timer to determine the length of time between transitions. The quantity of water for each transition must be defined in the microcontroller.

In order for the controller to calculate the amount remaining to water for each zone, the user must define the precipitation rates for each zone in the system. Some zones may not receive rain, such as in a porch or greenhouse. The user then needs to selectively disable the compensation for precipitation for those zones.

Wind Speed

Wind is a factor in the effectiveness of sprinklers. As wind speed increases, the rate of evaporation of water increases. The water being sprinkled can be blown away from where water is required to where no water was intended or needed. Many sprinkler specifications are given for a particular wind speed. Nelson sprinkler specifications assume zero wind.[4] Toro recommends reducing square sprinkler spacing from 55% of sprinkler diameter with zero wind to 45% with 8 m.p.h. of wind.[1]

No stand alone controllers were found with the capability of measuring and compensating for wind speed. Only irrigation systems with a dedicated PC as a central computer controlling one or more satellite controllers could measure wind.[1,2]

The most common device used to measure wind speed is a 3-vane anemometer. The anemometer spins more rapidly as wind increases. The output can either be a small generating device or a digital pulse for each revolution. An anemometer with a digital output was chosen. It requires one digital input and a timer to measure the time for each revolution.

Under high wind conditions, all sprinklers which are affected by wind should be paused. It is desirable to average the wind speed over a period of time to ignore wind gusts. When the wind falls below the specified limit for a period of time those sprinklers that were disabled may resume watering. If high wind conditions persist for a long period of time, an override should be provided.

Water Pump Control

Irrigation systems are designed to operate at some nominal water pressure. If the pressure is low, the sprinkler coverage may be incomplete. The most effective watering is when the water pressure is within design parameters. When a valve is first opened, there may be a sudden loss of pressure due to the water line having drained since the last use. If the water pressure is already low, the pump may have to operate for some time before adequate pressure is reached.

Water pump control is usually provided as a separate unit to control a pump dedicated to the irrigation system. The pump is normally turned on and off corresponding to valves being turned on and off. None of the irrigation controllers found in the research measured water pressure.

A system which controlled the pump based on a measured water pressure would conserve water and energy. The pressure should be above a minimum operating pressure before turning on a valve. While watering, if the pressure falls below a safe value, the valves should be turned off for the pressure to recover. If the pressure still does not rise, either the water well is low or the pump is failing. The pump should be turned off under this unsafe condition. After a recovery period, the pump could be turned on again once to check for adequate pressure. If normal pressure still cannot be achieved, the pump should be permanently disabled until the user corrects the problem.

This method of pump control requires one ADC input for water pressure and one digital output for turning on and off the pump.

Miscellaneous Features

The water and energy conserving features of the irrigation controller only supplement those features which must be present for a marketable product. Some of the basic attributes are:

- Clock with battery backup.
- Simple programmability.

- Insensitivity to power fluctuations.

A desirable feature would be the remote control of the irrigation controller. This would allow the controller itself to be wired in a less accessible location than the display and keypad.

CHAPTER 3 - CONTROLLER HARDWARE

The basic hardware was designed to operate as an eight zone irrigation controller with connectors for option boards. The overall hardware design is discussed followed by a detailed discussion of each circuit board.

Hardware Design

Figure 1 on page 11 shows the hardware block diagram for the controller. The basic controller consists of the main board, the options connector board, one 8-zone driver board, and a 24 Volt transformer.

Connectors on the options connector board and the main board allow the following options to be added to the controller:

- Up to two additional 8-zone driver boards.
- Ground moisture measurement.
- Precipitation measurement.
- Wind speed measurement.
- Radio frequency remote control.
- Weather station sensors (indoor and outdoor humidity and temperature, barometric pressure and wind direction.)

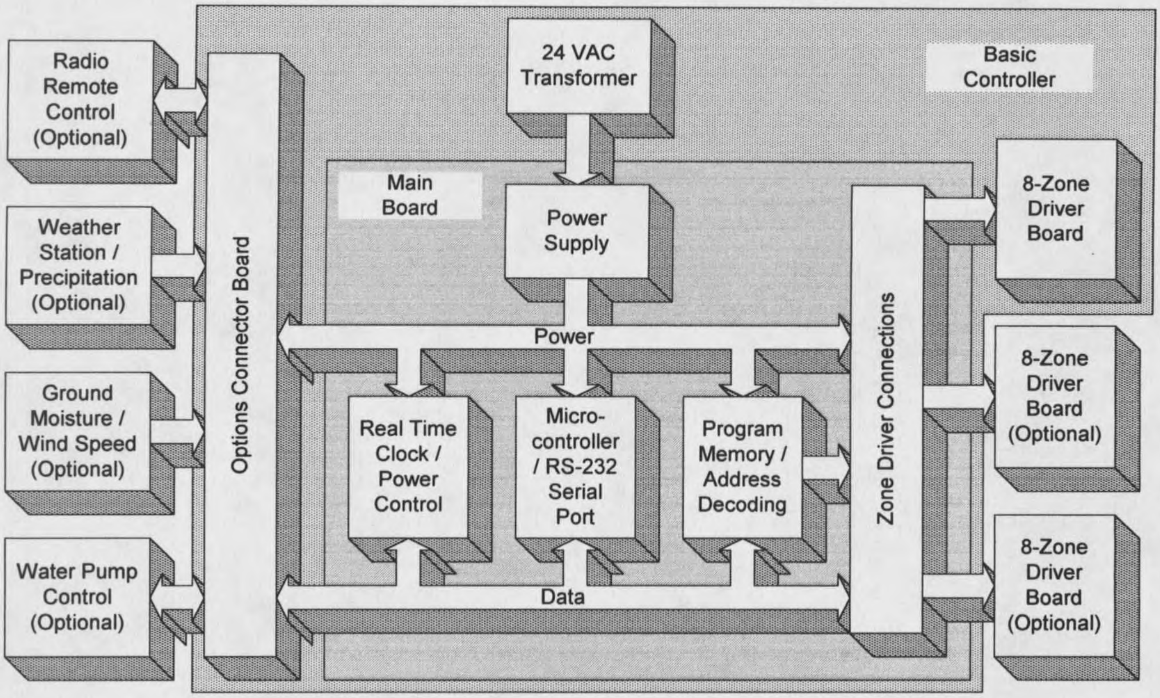

Figure 1. Controller Hardware Block Diagram.

Main Board

As shown in Figure 1, the main board has been divided into logical blocks. Each block and its associated schematic diagram is discussed separately.

Power Supply

Figure 2 on page 12 shows the schematic diagram for the power supply circuit. Power is supplied from a 24 *VAC* (Volts Alternating Current) center-tapped transformer. The electric current requirement of the transformer is dependent on the number and type of electric valves to be turned on at once and the various options connected to the controller. For a typical home irrigation system, one drip irrigation valve and one sprinkler valve may both be on, in addition to a master valve. Most commonly available valves draw 0.50 *A* (Amperes) or less of inrush current.[1,2,4] The controller itself draws 0.15 *A* of current under normal operation. Allowing for a margin of safety, the transformer's current rating should be at least 2 *A*.

28 *VAC* was assumed as the maximum supply voltage to allow for high line voltages and poor tolerance transformers. The peak voltage, V_{pk}, is given by:

$$V_{pk} = V_{rms}\sqrt{2} = 28V \times 1.414 = 39.6V$$

Due to the center tap, half of the peak voltage (19.8 *V*) will appear at the inputs of the full-wave bridge rectifier formed by D04 through D07. Two transient voltage suppressors (TVS1 and TVS2) protect the controller from voltage spikes exceeding 20 *V*.[12]

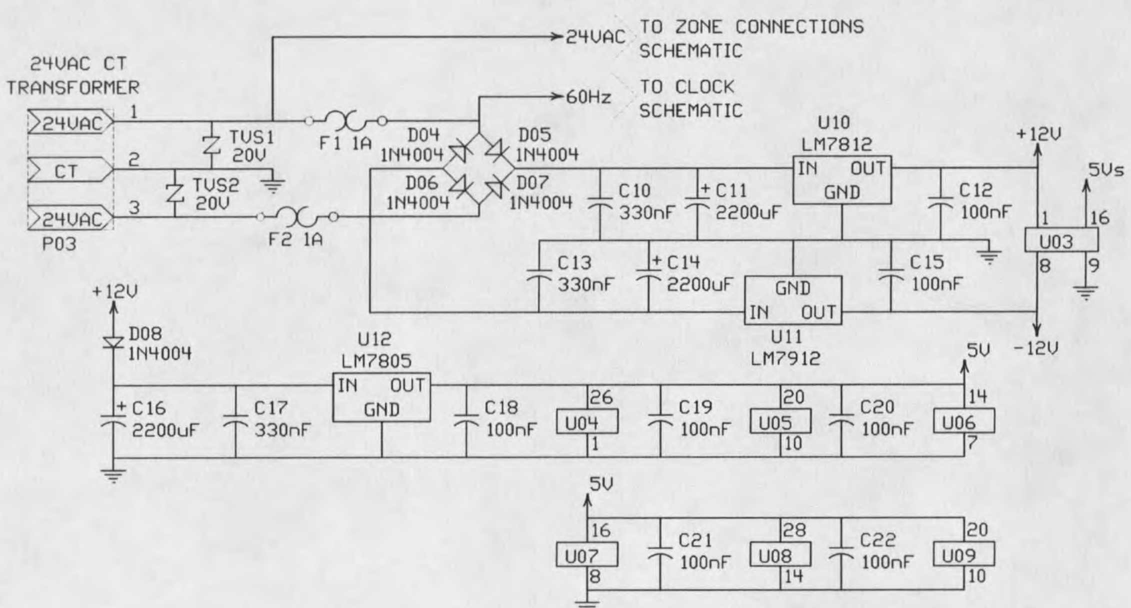

Figure 2. Power Supply Schematic Diagram.

U10 and U11, along with their associated capacitors, provide plus and minus 12 *VDC* (Volts Direct Current) to the circuit.

In the case of a power failure, rectifier D08 allows capacitor C16 to provide current to the microcontroller until the capacitor charge is depleted. The voltage available for the 5 *V* voltage regulator is 12 *V* minus the voltage drop across the rectifier, minus the dropout voltage across the regulator itself, minus the output voltage of 5 *V*. The maximum instantaneous forward voltage drop across a 1N4004 is 1.1 *V*.[13] The dropout voltage for the LM7805 voltage regulator is 2.0 *V*.[14] Assuming the measured controller current draw of 0.15 *A* is constant, the time available for the microcontroller to prepare for the power failure is given by:

$$I = C\frac{dV}{dt} \Rightarrow dt = C\frac{dV}{I} = 2200x10^{-6}\,F\frac{12V - 1.1V - 2.0V - 5.0V}{0.15A} = 57.2m\sec$$

57.2 milliseconds allows for the completion of any write to EEPROM currently in progress (maximum of 10 msec.) and execution of approximately 17,400 instructions before power is lost.

Real Time Clock / Power Control

Figure 3 shows the schematic diagram for the real time clock and power control circuit. The real time clock is a Motorola MC68HC68T1P.[15] Operations performed by the clock are:

- Keeping time and date.
- Power supply monitoring and control.
- Microcontroller reset control.
- Microcontroller interrupt at time intervals and power failure.
- Data transfer to and from the microcontroller.