Drip Irrigation System using BLDC Motor-driven Direct Pumping and Soil Moisture Sensor

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***Abstract*- Drip irrigation system is very efficient in irrigating vegetables and crops. Conventional drip irrigation systems provide water to crops based on predetermined doses and schedules regardless of farmland conditions. Drip irrigation control that ignores soil conditions causes too little or too much water to be supplied which makes conventional drip irrigation still not optimal. This condition can be optimized by adjusting water supply according to soil conditions. In this study, drip irrigation is controlled by a Proportional-Integral (PI) control system using information from soil moisture sensor as a feedback signal. This system uses pressurized water generator from direct water pumping driven by brushless DC (BLDC) motor. Combination of PI control, soil moisture sensor and BLDC motor driven pump makes this system more efficient in using water and electricity than conventional drip irrigation systems. In the future, this drip irrigation system will be combined with solar panels to make it more efficient.**

Keywords - BLDC motor, Drip irrigation system, Proportional Integral control, Soil moisture sensor

I. INTRODUCTION

Irrigation has an important function in crop growth and agricultural production costs. Traditional irrigation has low efficiency in use of energy and water, this result in high production costs. Amount of excess water in crops can cause soil washing, fertilizer loss and increased soil salinity [1]. This condition can be reduced by providing enough water to crops according to their needs.

Each crop has a different level of water needs at each stage of its growth. Precision irrigation can provide water according to crop needs and environmental conditions. Drip irrigation is one of precision irrigation that is widely applied today. Control of drip irrigation aims to regulate droplet discharge and volume of water given to crop according to its dosage. This system drips water at a low rate (2-20 liters/hour) through an emitter. This irrigation can prevent soil erosion, save water and fertilizer. The irrigation is very efficient because water seeps into the ground before it evaporates and seeps around the roots of plants. Duration of water droplets keeps soil around crop moist and good for growth.

Indonesia as an agricultural country still uses a lot of surface irrigation, so cost of agricultural production is expensive. Indonesian government through several research centers has begun to apply drip irrigation. One of research centers is Center for Horticultural Crop Technology Development in East Java Province. At the research center, the developed drip irrigation system still uses conventional controls. In the conventional controls, volume of water given to crops is measured based on duration of irrigation in which emitter discharge is assumed to be constant. This method is very commonly used because it is easy to implement. However, this method is still not efficient in which a lot of water is wasted because it exceeds the needs of crops. Moist soil requires less water than dry soil. Therefore, right method for controlling water irrigation is based on level of soil moisture around crop. This control system may use soil moisture sensors as feedback.

Control of automated drip irrigation based on timers or soil moisture sensors has been studied by several researchers, including: an automation system for drip irrigation using a single board computer to control water flow regulator valve via e-mail [2], drip irrigation systems that have ability to learn and make decisions based on processing data from several types of sensors [3], pressure of drip irrigation remains constant even though irrigation capacity changes [4], control of drip irrigation automatically with a moisture sensor [5]. One of the conclusions of their study is that drought occurs because water supply to crops is less than the minimum amount of soil moisture for the crops.

In general, studies related to drip irrigation control with moisture sensors still uses an induction motor driven water pump. Induction motors have relatively low efficiency, so they consume more electrical energy than Brushless DC motors (BLDC) [6]. Electricity consumption is related to production costs. Stability of irrigation system's emitter discharge is usually not carried out in the studies. Emitter discharge that is too varied can produce excess water beyond crop's water requirements [7].

Drip irrigation in this study uses a direct water pumping system driven by BLDC motor. Amount of water given to crops is based on water need of a crop and soil conditions measured by moisture sensors. Emitter discharge is kept constant with a water pressure controller. Constant discharge of emitters supports accuracy of water volume given to the crops. This system has a higher efficiency than an irrigation system that uses timer-based controls.

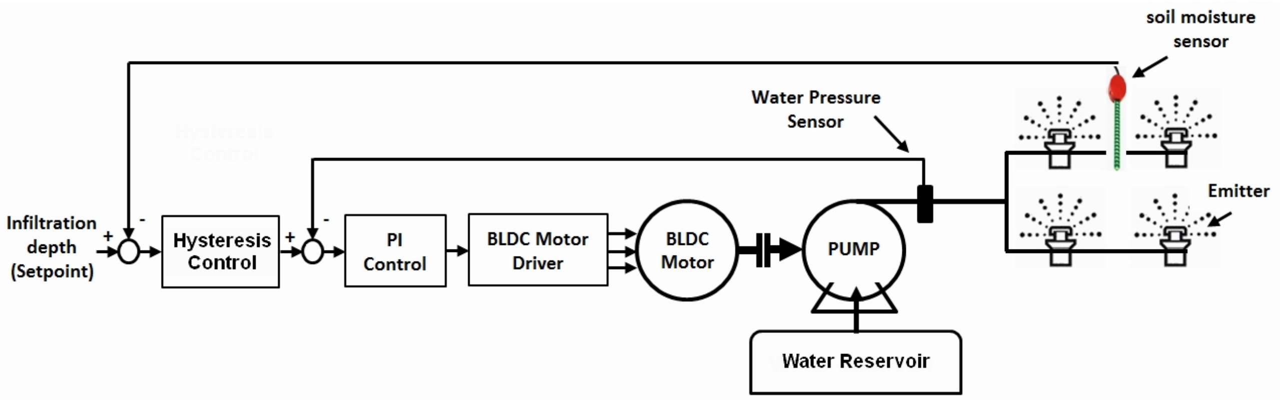

Fig. 1. Functional diagram of drip irrigation system with a feedback of soil moisture sensor.

II. MODEL OF IRRIGATION SYSTEM

This drip irrigation system that uses a humidity sensor as feedback has three main parts, namely a water pressure control system, a water distribution network and a humidity sensor. Water pressure control system aims to keep water pressure constant even though irrigation load changes. Water pressure is controlled by adjusting speed of water pump through setting BLDC motor speed. Closed loop control uses Proportional-Integral method with feedback from water pressure sensor installed in main pipe. The water distribution network consists of several lateral pipes that have several emitters. Irrigation volume is controlled using a hysteresis method with a feedback signal from soil moisture sensor. Sensor is installed near roots of crops to measure depth of water absorption around roots of the crops. Functional diagram of drip irrigation system with feedback signal from soil moisture sensor is shown in Fig. 1.

A. Drip Irrigation Load Model

Type of the crop in this study is chili. Chili has crop evapotranspiration (ETc) of 24.2 mm/day. Number of crops in land is 300 crops. Emitter discharge is 4 liters/hour with an irrigation period of 10 days. Distance between crops is 0.5 m and the lateral distance is 0.7 m. The water pressure of irrigation is 12 Psi or the head of 8.44 m. Based on these data, droplet emitter (EDR) rate is 8.44 mm/hour. Duration of irrigation operations for each day based on equation (1) is 0.21 hours or 12.6 minutes.

$$Irrigation\ Operation\ Time = \frac{Crops\ Water\ Needs}{EDR} \quad (1)$$

Irrigation discharge for 300 crops is 0.00033 m^3/s. Water pump needed by system based on equation (2) is 63.5 watts.

$$W_{water\ horsepower} = \rho g H_p Q_p \quad (2)$$

where $W_{water\ horsepower}$ is output power of pump (watt), ρ is density of fluid (kg/m^3), Q_p is water flux (m^3/s), H_p is total head (m) and g is gravity acceleration (m/s^2) [6].

B. Model of Centrifugal Water Pump driven by BLDC.

This pump driven irrigation system uses a centrifugal pump. The pump has characteristics as shown in Fig. 2. The pump is driven by a BLDC motor which has characteristics as shown in Table 1. The BLDC motor driver uses a six-step method in which the motor speed is controlled by adjusting the DC source voltage level. Integration model between the motor and the water pump is shown in Fig. 3. Simulation result of the centrifugal pump driven by a BLDC motor is shown in Fig. 4.

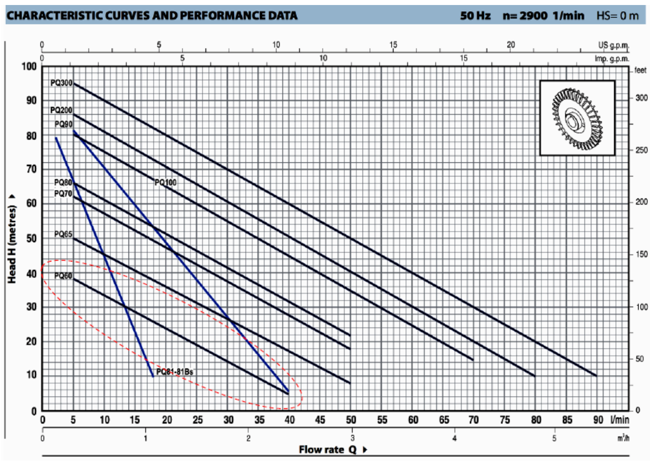

Fig. 2. Characteristics of Pedrollo PQ60 centrifugal water pump.

TABLE I. BLDC MOTOR SPECIFICATIONS.

Parameter	Unit	BLY344S-48V-3200
Vendor		Anaheim Automation
Rated Voltage	V	48
Rated Speed	RPM	3200
Rated Power	W	660
Back EMF Constant	V/kRPM	9.07
Electrical Poles		8
Phase Resistance	Ohms	0.07
Phase Inductance	mH	0.1
Rotor Inertia	In-oz-sec^2	0.03399

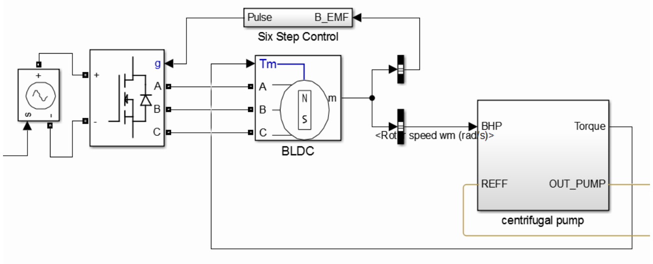

Fig. 3. Model of integration of the water pump and the BLDC motor.

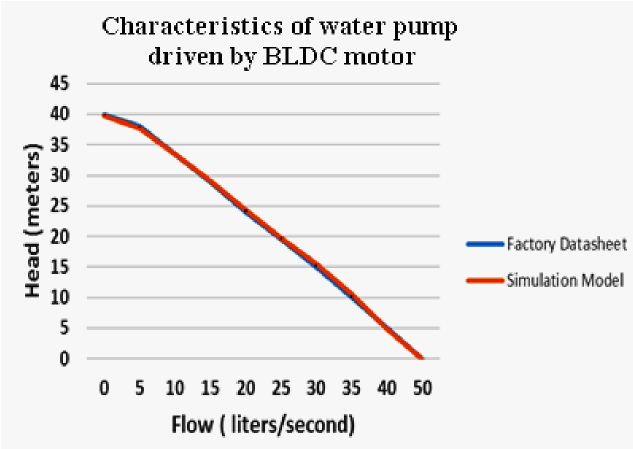

Fig. 4. Characteristics of water pump driven by BLDC motor.

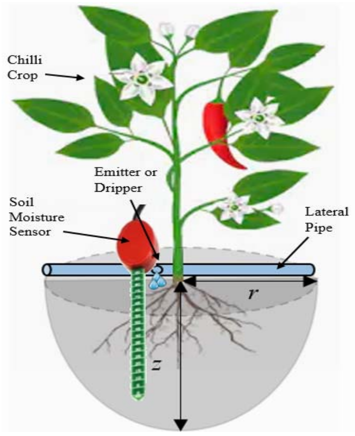

Fig. 5. Infiltration geometry pattern and position of soil moisture sensor.

C. Soil moisture sensor model.

Soil moisture sensor is a sensor to determine depth of water absorption around emitter droplets. In this simulation, we need water distribution pattern and wetting pattern under drip irrigation. Many researchers develop mathematical models that are quite complex and require detailed information about nature of soil. Simple empirical models for determining leach geometry patterns are more often used than dynamic models [8]. In this study, water absorption geometry patterns were used as a model of soil moisture sensors. Illustration of geometric pattern of infiltration and position of soil moisture sensor is shown in Fig. 5.

Based on recharge geometry pattern introduced by Shwartzman and Zur, relationship between droplet discharge and absorption radius (r) and into recharge (z) is formulated in equations (3) and (4).

$$r = \theta^{-0.5626} V_w^{0.2686} q_w^{-0.0028} k_s^{-0.0344} \tag{3}$$

$$z = \theta^{-0.383} V_w^{0.365} q_w^{-0.101} k_s^{0.195} \tag{4}$$

where, r is wetted soil radius (m), z is vertical distance of wetted soil (m), V_w is volume of applied water (L), k_s is saturated hydraulic conductivity of soil (m/s), and q_w is point-source emitter discharge (L/hr). In this simulation model, value of k_s is 8.39 m/s and q_w is 0.48 L/hr. Model verification is accomplished by comparing the pattern of simulation and real observation [8].

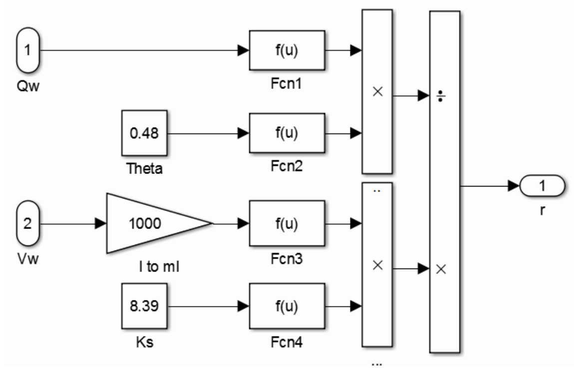

Fig. 6. Model of infiltration from a point source drip.

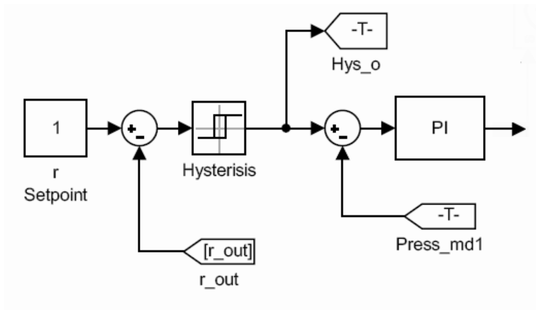

Fig. 7. Model of water pressure control system using cascade control.

TABLE II. OPEN-LOOP ZIEGLER-NICHOLS SETTING

Controller	Kp	Ti	Td
Proportional	Ti/(K Td)		
PI	0.9 Ti/(K Td)	3.3 Td	
PID	1.2/(K Td)	2Td	0.5Td

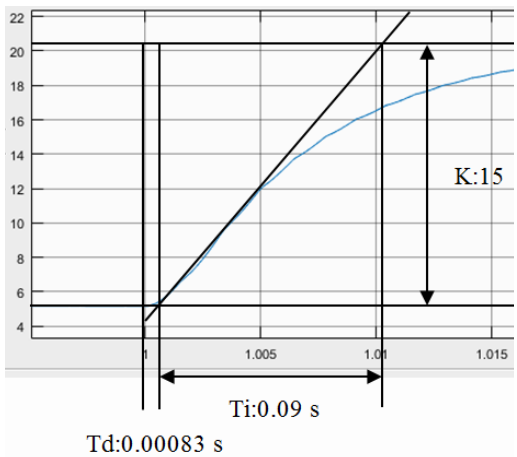

Fig. 8. Transient response of drip irrigation system in open loop configuration.

Variable value that is used as a feedback signal controller is the depth of recharge. Simulation diagram of recharge distribution model is shown in Fig. 6.

D. Pressure Control and Infiltration depth Control

Drip irrigation controller in this study uses cascade control method, as shown in Fig. 7. This method consists of water pressure control and water infiltration depth control. The control of irrigation water pressure uses Proportional-

Integral (PI) method. The PI control strategy is chosen because it has immunity to variations in plant parameters that lead to invariant dynamics and static responses [9].

The PI control regulates the motor voltage which results in a change in motor speed which will result in changes in water pump discharge and then in irrigation network pressure. Control of the water infiltration depth uses hysteresis method. In this control, the value of soil moisture is compared with the expected water infiltration depth. If the infiltration depth of water has been reached, the irrigation process is stopped. Hysteresis control parameter has a bandwidth of 0.01.

Determination of PI control parameters are using Ziegler-Nichols method as shown in Table 2. Values of K, Ti and Td are obtained from transient response of the open loop system with input voltage from 10V to 20V as shown in Fig. 8. Based on the response, K and Ti are obtained at 6.5, and 2.74 ms, respectively.

Simulation diagram of drip irrigation system with timer-based control is shown in Fig. 9. Duration of crops irrigation in this system is based on a predetermined setpoint of timer. Simulation diagram of drip irrigation system with direct pumping with soil moisture sensor is shown in Fig. 10. If the water infiltration has reached the distance setpoint, the water supply to crop is stopped. Initial condition of water content in soil is regulated by the value of r0. If initial conditions of the soil are wet, the water demand will decrease.

III. Result and Discussion

Simulation results of the drip irrigation system controlled by timer are shown in Fig. 11. The system uses a fixed volume of water in each irrigation period. Volume of water is based on ideal calculation of needs of the crops with an initial infiltration depth of 0.2 cm. In accordance with equation (1), duration of irrigation is 0.21 hours/day or 756 seconds. The discharge in each emitter is 4 liters/hour and volume of water given to the crop is 0.84 liters. Infiltration depth radius is 1.64 cm. Total volume of water used to irrigate 300 crops is 252 liters. The simulation results show that after irrigation period of 756 seconds, the infiltration depth is 1.326 cm with the water volume of 0.819 liters. This mismatch is due to ripples in water pressure that affect emitter's discharge. Ripples at the water pressure are caused by large sampling times. Total electrical energy used in this overall irrigation is 4.8 Wh.

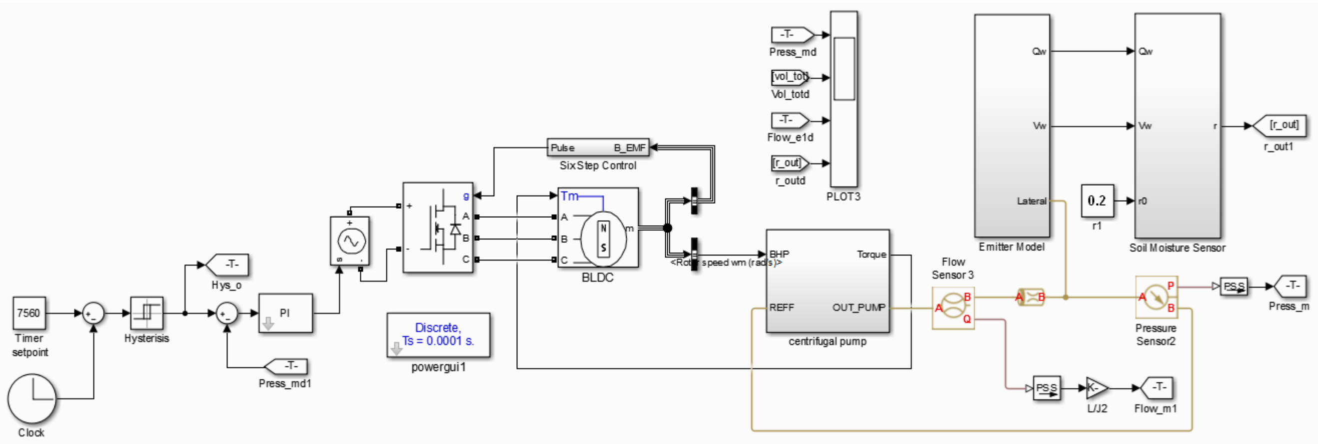

Fig. 9. Simulation diagram of drip irrigation system with timer-based control.

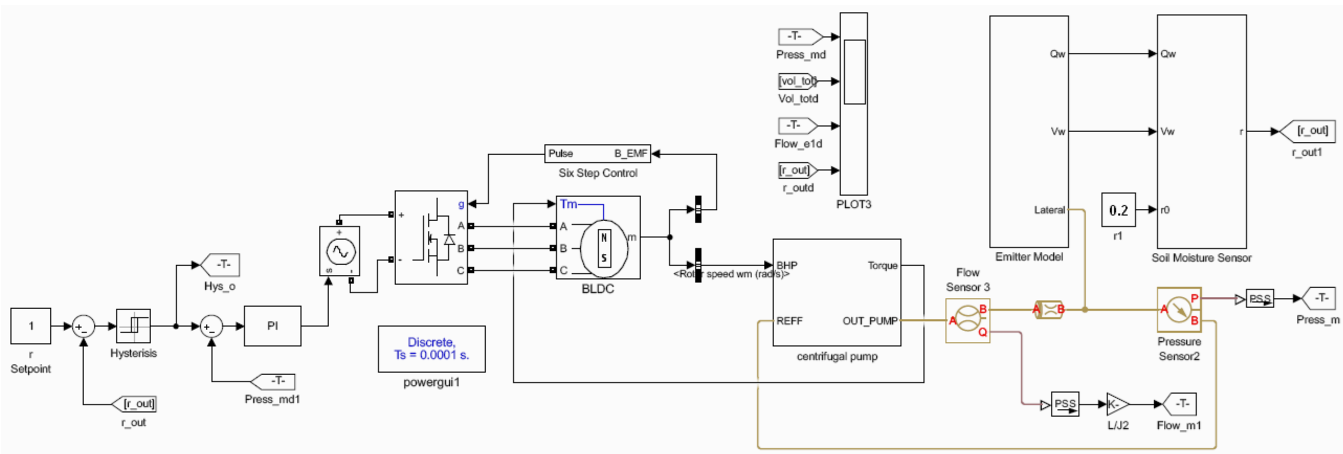

Fig. 10. Simulation diagram of drip irrigation system with direct pumping with soil moisture sensor.

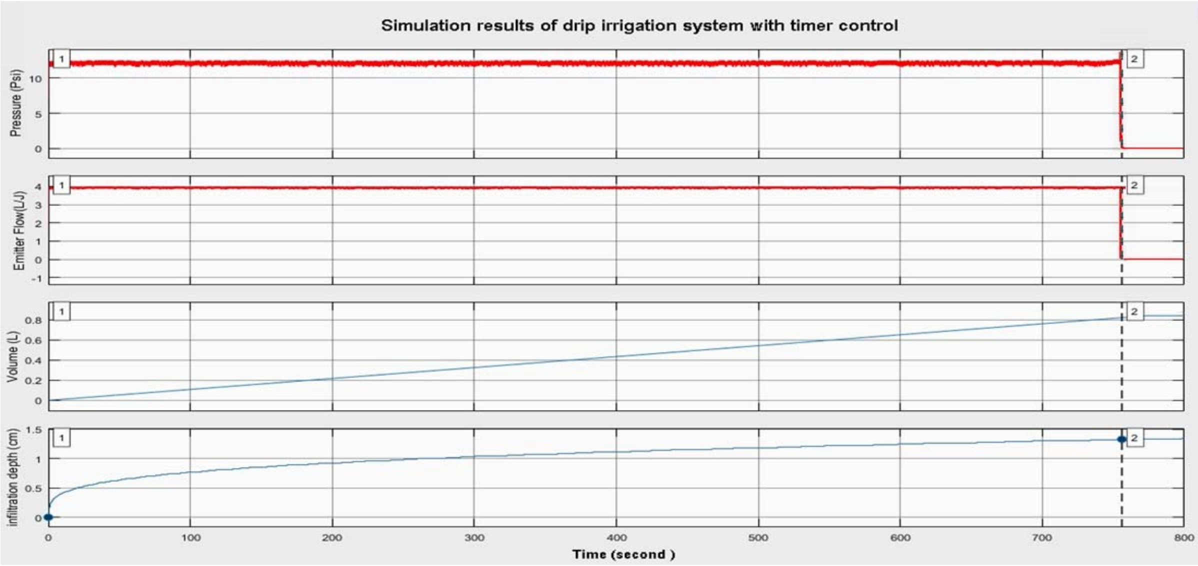

Fig. 11. Simulation results of drip irrigation system with timer-based control.

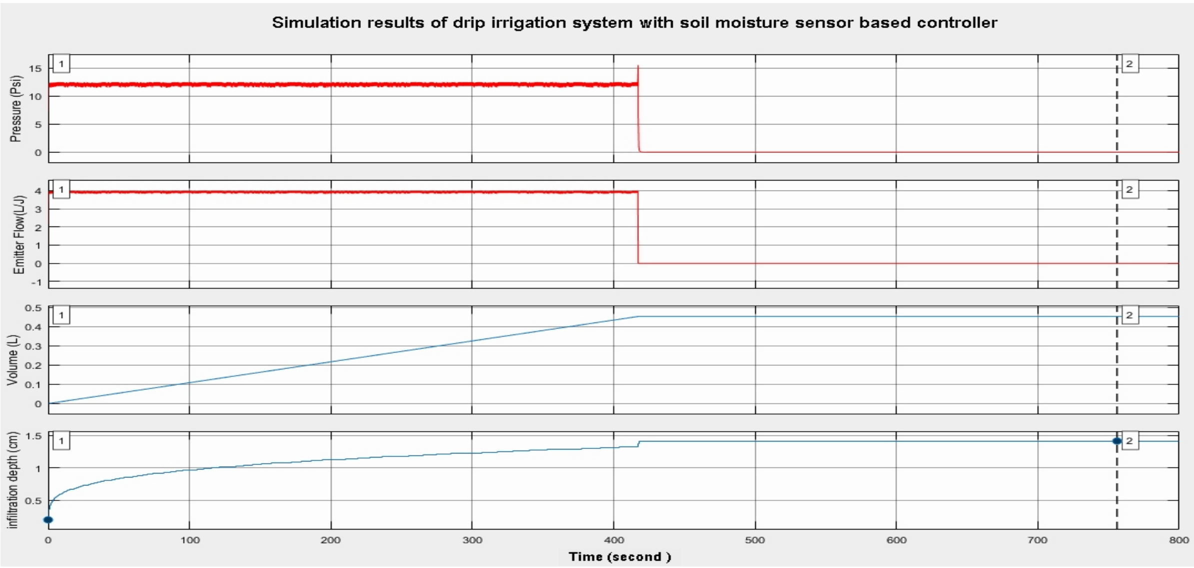

Fig. 12. Simulation results of drip irrigation system with direct pumping with soil moisture sensor.

Fig. 12 shows simulation result of the drip irrigation which is controlled based on soil moisture sensor with initial infiltration depth of 0.2 cm. Drip irrigation with sensor-based control will stop giving the water after depth of water infiltration matches the setpoint. When infiltration depth is reached, the system closes the valve and stops the pump. This saves significant water and electricity energy. With an initial depth of 0.2 cm, this system can save 0.388 liters/emitter or 116.4 liters for 300 crops. Total electrical energy used in this overall irrigation mechanism is 2.99 Wh. Therefore, this system can save 1.86 Wh or 38.32 % more efficient.

IV. Summary

In this study, we compare drip irrigation systems driven by Brushless DC motor between time-based control and soil moisture sensor-based control. Irrigation system with time-based control requires a fixed amount of water and electricity for each irrigation period, while the drip irrigation system with soil moisture sensor-based control requires different amounts of water and electricity for each irrigation period according to conditions of planting media. The water pressure control uses Proportional-Integral method while the water supply control uses hysteresis control. The PI control parameters are determined using Ziegler-Nichols method. The results show that the closed-loop control system is more efficient in requiring amount of water and energy of 46.2% and 44.8%, respectively.

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