AUTOMATION OF UNDERGROUND CABLE LAYING EQUIPMENT USING PLC AND HMI

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Abstract. Underground cable laying is an alternative for overhead cable laying of telecommunication and power transmission lines. It is becoming very popular in recent times because of some of its advantages over overhead cable laying. Underground cable laying is mostly practiced in developed countries because it is more expensive than overhead cable laying. Underground cable laying is more suitable when land is not available, and it also increases the aesthetics. This paper implements the automation on a manually operated cable pulling winch machine using programmable logic controller (PLC). Winch machines are useful in underground cable laying. The main aim of the project is to replace all the mechanical functions with electrical controls which are operated through a touch screen (HMI). The idea is that the machine should shift between parallel and series circuit automatically based on the pressure sensed instead of manually operating the solenoid valve. Traditional means of throttling the engine using lever and wire is replaced with a linear actuator. Sensors such as proximity, pressure and load sensor are used to provide the input to the system. The HMI used will display the speed, length and tension of the rope being winded. Ladder logic is used to program the PLC.

Key words: Manufacturing of cable laying equipment, hydraulic circuit, PLC, HMI, automation and product development.

1. Introduction:

Automation in the industry becomes the global trend in manufacturing and with the success of the Japanese and European industries in terms of production; more and more companies are switching to automation. [1] Automation has the ability to make machines smart, well at least as smart as the programmer wants them to be. To automate a machine, a brain of some sort is needed which is the PLC in the present case. With the help of a PLC, a machine can handle processes without much of human interference. Whether the process is too fast, slow, small, big, cold, hot or just too dangerous for humans then an automated machine is the solution. Jonathon C. Ralston, has developed and implemented a longwall automation technology to achieve greater levels of underground coal mining performance [2]. In order to increase system safety and productivity Janne Koivumaki has worked on High performance nonlinear motion/force controller design for redundant hydraulic construction crane automation [3]. M. Allain, has researched on Blended Shared Control of a Hydraulic Excavator. An automatic control may be able to execute some quasi-repetitive construction tasks more efficiently than a human. This dichotomy has led to interest in Shared Control (SC) which synthesizes the advantages of both autonomous and manual control of machinery. A particularly interesting case of SC for unstructured environments is called Blended Shared Control (BSC) where weighted inputs from the human operator and autonomous controller are continuously combined to perform a task [4].
A.V. Averchenkov, has researched on automation of engineering preparation of volumetric hydraulic actuator production in a small company [5]. A. Selwin MichPriyadharson has implemented PLC – HMI Automation Based Cascaded Fuzzy PID for Efficient Energy Management and Storage in Real Time Performance of a Hydro Electric Pumped Storage Power Plant [6]. G. Prinsloo, has used PLC control strategy in solar power system automation for optimizing carbon footprint [7]. The machine and plant automation domain is faced with an ever increasing demand for ensuring the adaptability of manufacturing facilities in context of Industry 4.0. Christoph Legat, A configurable partial-order planning approach for field level operation strategies of PLC-based industry 4.0 automated manufacturing systems is developed [8]. Agostino, describes an automation scheme using levels of hierarchic control and distribution of the operation of information using PLC [9]. Laura Gröhn, presented a case study of developing a distributed factory automation system model upgrade with decentralized control deployed on a network of six programmable automation controllers communicating wirelessly [10].

The main features are that the operating system is hassle free and safe, more efficiency, less response time and reduced number of labours. The most important advantages of automation are accuracy, lesser time and almost no errors. This completely automated winch machine is the first of its kind.

2. Cable Pulling Winch Machine:

ELFIT ARABIA, UAE is one of the leading Cable laying equipment manufacturers and suppliers in the Middle East for last few decades. Cable laying equipment include Rollers, Winch Machines, Cable Drum Trailers and many more cable laying accessories as shown in the Figure 1 below.

![Figure 1](image_url)

Rollers, trailers and winch machine are the most important equipment’s that are used in underground cable laying process. Rollers are used to avoid friction while pulling the cable using winch machine so that the cable doesn’t undergo any damage, i.e it acts as a solution for guiding and protecting cables. Cable Drum Trailer is used for easy transportation of cable drum from store to site. Cable pulling Winch machine is an underground cable laying equipment used for laying telecommunication and power cables under the ground. Below figure explains the process of cable laying using rollers, trailer and winch machine.
Winch machine is a hydraulic machine powered by either electrical motor or thermal engine. Figure 3 is the line diagram for the cable pulling winch machine. In the figure red lines represent mechanical connections, green lines represent hydraulic connection and the parallel lines represent power transmission.

Engine is the primary source in the system which powers the hydraulics, engine is coupled to the hydraulic unit pump. Mechanical Power generated in the engine is transferred to the pump and gets converted to hydraulic power. Hydraulic power from the pump is transferred to the motors for rotating the capstan and drum connected to them.

Figure 4 is a detailed explanation of how metal rope connects capstan, level winding mechanism and the drum. Metal rope enters the capstan, wounds on the capstan then exists from the capstan, enters the level winding mechanism and then on to the drum. Drum is used to stores the rope on it. Capstan is used to pull the rope in tension and level winding mechanism guides the rope from the capstan to the drum.

There are two main operations of a cable pulling winch machine namely Pull-in and Pull-out. In pull-In operation, rope is pulled into the system. Capstan and Drum rotate in clockwise direction. Rope is pulled into the machine. Pull In operation can be seen in figure 5.
In Pull-Out operation rope is pulled out of the machine. Here Capstan and Drum rotates in anti-clockwise direction. Rope is pushed out of the machine. Pull out operation can be understood from figure 6.

Figure 5. Pull in process

Figure 6. Pull out process

Figure 7 represents the hydraulic circuit for the manually operated machine. It is a closed loop circuit. The circuit inside the dotted box is bi directional variable displacement closed loop pump. A 4/3 NC Directional control valve represented as 1 in the figure is used to change the direction of the pump flow and a flow control valve is used to control the pilot pressure to the pump. Displacement of the pump is directly proportional to the pilot pressure. Three fixed bidirectional motors of same capacity, one for drum and two for capstone are used. Let’s say Motor attached to the drum is called drum motor and the motor connected with the capstan is called capstan motor. Two 4/2 directional control valves are arranged between the capstan motors to connect the capstan motors in either parallel or in series. In parallel connection input of first motor is connected to the input of the second motor and output of first motor is connected to the output of the second motor. In series connection input of one motor is connected to the output of the other motor.

The primary driver behind the research and development of automating the winch is to increase the safety, productivity and efficiency of the machine.

3. Automation of winch:

In the new hydraulic circuit (as shown in figure 8) which is going to be automated, all manually operated valves are replaced with electrically controlled solenoid valves. 4/3 manual controlled valve is replaced with 4/3 electro proportional valve. 4/2 manually operated directional control valves are replaced by 4/2 electrically controlled valves.
Figure 7. Hydraulic circuit for manually operated winch

Figure 8. Proposed hydraulic circuit of automated Winch

The throttle lever used to adjust the engine speed is replaced by a linear actuator. All the controls are controlled using PLC and HMI. Using the HMI, functions like switching ON and OFF of the machine, pull-in and pull-out, switching between series and parallel of the circuit can be controlled. Using the information from the sensors, PLC calculates speed, length and tension in the rope being pulled and displays it on the HMI screen.

To automate the machine the PLC is programmed in such a way that the machine switches between series and parallel sensing the pressure in the system. Automation is done using the following components.

3.1 PLC implementation:

As the need of automation increases significantly, a control system needed to be easily programmable, flexible, reliable, robust and cost effective [11]. A programmable logic controller is an industrial computer. This digital computer has been designed to perform reliably under harsh environmental conditions like exceedingly hot or cold temperatures, dusty and wet conditions and strong reverberations. The way the PLC functions has been expanding to include sequential relay control, motion control, process control and networking. The potential of some modern PLC’s processing power, storage, data handling and communication skills are roughly equivalent to desktop computers. The language used to program the PLC in the present project of automation of winch is ladder logic. PLC works with digital and analog input and outputs. Figure 10 explains how different components are connected to the PLC.

3.2 HMI:

Human machine interface in the industrial world is the means through which communication between humans and machines take place. Recent development in Human Machine Interface (HMI) have brought remarkable advances in performance, flexibility and openness [12]. The main aim of the HMI is to accomplish simple control of the machine and to display the information of the process. Design of the HMI should be user friendly, self-explanatory and productive to operate the machine in such a
manner that it produces the desired result, which means the input to the machine should be minimal. The user interface in our project is a touch screen that is attached to the PLC. Fig 9 below shows the HMI display.

![HMI display](image)

**Figure 9.** HMI displaying various parameter and bottoms to control the machine

![Connection diagram](image)

**Figure 10.** Connection of different components to the PLC

### 3.3 Load cell:

A load cell is a transducer that produces electrical signals when force is applied on it. The most commonly used load cell is strain gauge. When force is applied on the cell it deforms the strain gauge.
This strain is measured as a change in electrical resistance. Load cell generally consists of four strain gauges in a Wheatstone bridge structure. The output from the load cell must be amplified as the electrical signal from the load cell is in millivolts. The amplified output must be scaled to compute force applied on the load cell. There are four wires from the load cell coloured as red, black, white and green and should be respectively connected to excitation+, excitation-, signal+ and signal- of the load cell amplifier respectively. Output from the amplifier is 0-20mA powered by a 12V Dc supply. Figure 11 explains the connection of load cell with amplifier and PLC.

![Diagram](image)

**Figure 11.** Connection of Load cell with PLC

### 3.4 Proximity sensor:
The key function of a proximity sensor is to detect the presence of object without being in contact with them. Compared with more sophisticated sensors, proximity sensors have the advantage of having lower costs and lower energy consumption, but also the disadvantage of being less accurate [13]. From the wide ranges of proximity sensors digital inductive proximity sensor is used in the machine. Inductive proximity sensors are used to detect the presence of metals. Since it is a digital sensor it has just two states – On/Off, detects the presence or absence of the object. Proximity sensor in our system is used to calculate the winding speed of the machine. This in turn calculates the length of the rope. This sensor is connected to the digital I/O of the PLC. The +24VDC of the sensor goes to the +24VDC of the PLC and the +VE of the power supply, and the output of the sensor goes to the PLC input. Connections of the proximity sensor to the PLC are given in the figure 12.

### 3.5 Linear actuator:
Electric linear actuators convert the rotational motion of a low voltage DC motor into a linear push and pull motion. Electric linear actuators allow the operators of the machine an exceptional choice of control, for superior efficiency, safety and sustainability. Actuators allow more ergonomic setting of controls for less operator fatigue and more responsive operation. When linear actuators are interfaced with electronic controls this enables automatic speed adjustments, lesser fuel consumption, and better noise management and reduces downtime and operator fatigue. The end result is that off-highway equipment vehicle manufacturers can deliver a better product with a competitive advantage [14]. The linear actuator in our system is connected to the throttle to control the engine speed of the winch machine. By connecting the actuator with two relays, polarity of the actuator can be changed to get forward and backward motion of the actuator.
3.6 Solenoids:
A solenoid valve is an electromechanical actuated valve used to control the flow of liquids and gases. They are used to close, distribute or mix the flow of gas or liquids. The definite purpose of a solenoid valve is defined by the way its circuit functions. A 2/2 way valve contains two ports (inlet and outlet) and has only two positions (open or closed). A 2/2 valve can be 'normally closed' (closed in de-energized state) or 'normally open' (open in de-energized state). A 3/2 valve contains three ports and two positions and can hence switch between two circuits. 3/2 way valves can have distinct functions such as universal, diverting, normally closed and normally open.

3.7 Pressure sensor:
They are also known as pressure transducers or pressure transmitters. Pressure sensors measure the pressure and give a proportionate analog electrical signal as the output. The analog to digital convertor in the PLC converts the input analog signal to numbers which are displayed on the HMI screen. Figure 13 shows the connection of a pressure sensor to PLC.

3.8 Printer:
The printer is connected to the PLC by a RS232 cable. All the values of the parameters displayed on the HMI can be printed directly from the machine. The printed slip will show the Company name,
project name, date, time, length, speed and load. Figure 14 explains the connection of printer with HMI.

4. Logic:

To automate the winch machine, the language used to program the PLC is ladder diagram or commonly called ladder logic. The name is based on the observation that the program in this language resembles ladders, with two vertical rails and a series of horizontal rungs between them [15]. Since the PLC was developed to replace relay logic control systems, it was only natural that the initial language closely resembles the diagrams used to document the relay logic. The rungs in the ladder diagram contains program statements. A program statement is basically a condition or a set of conditions (inputs). Each of these conditions has an action (output) associated with them that is executed if the condition is satisfied. Elementary logic operators like AND, OR and NOT are used to perform logic operations required by the PLC [16]. The logic behind the automation of the winch machine is explained below.

As shown in the figure 15, When the machine is switched on, the instantaneous speed is calculated using the proximity sensor. As speed is known, instantaneous length is calculated simultaneously. The next step is for the user to decide if the machine is supposed to wind in rope or wind out. Input is given through HMI. Based on the selection the solenoid is activated and the machine pulls in the desired direction. As the machine winds the total length of rope being pulled in or pulled out is calculated. In case of winding in, if the rope length decreases to 0 m, the winding operations stops. If the machine is winding out, the total rope length should not exceed 1000 m. If it does the winding operation stops. This logic is for the automated cable pulling function of the machine.

Another logic runs simultaneously . When the machines switches on, the PLC checks if the machine is in 2.5 ton mode or 5 ton mode and accordingly executes the respective circuits. Here 2.5 ton means series connection and 5 ton means parallel connection. As shown in the figure 16, if the machine is in 2.5 ton mode, the pressure is sensed using a pressure transducer and checked by the PLC. If the pressure exceeds 250 bar, neutral is switched on. When neutral is switched on, pull-in and pull-out are switched off. The machine then switches to 5 ton mode and pull-in switches on again. Similarly, when the machine is in 5 ton mode, pressure is sensed by the transducer and checked by the PLC. If the
When automation of the winch machine was completed, it was decided to take the control one step ahead. The machine should be remotely accessed as shown in figure 17. The PLC is connected to a router and a web server is created to control the machine from a mobile, laptop, tab etc. The purpose to remotely access the machine is not just to make controlling easier but also to observe the data generated and understand what is happening on the site.
5. Conclusion:

This paper has attempted to implement automation on a manually operated winch machine using PLC, HMI and sensors. An overview of the working of automated winch machine is explained.

Further automation of the machine can be done by incorporating PID controller in PLC. This eliminates the need of an operator for controlling the machine. To enhance the usage of remote access, an IP camera along with an audio device can be installed in the machine.

PLC can be programmed further to make a self-troubleshooting machine.

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