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DESIGN OF A CONTROL AND DATA ACQUISITION SYSTEM FOR A MULTI-MODE SOLAR TRACKING FARM

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Abstract

This paper presents a combination network design for a solar tracking farm consisting of n-solar tracking systems. Serial communication protocol has been adopted for this network with developed strategy to make the farm expandable for possible future extension. The master control unit is responsible for managing all the trackers of the sun location in multi-tracking mode, diagnosis all the trackers for any faults and give complete information about the produced power by each of the solar tracking system. This network protocols is designed to deal with the error control, congestion control and flow control for data transmission in the network.

Keywords: Solar farm, dual axis solar tracker, microcontroller, embedded system, data acquisition

1. Introduction

There are various types of PV sun tracking systems. With dual-axis tracking the system always maintains the optimum system alignment to the sun. If higher voltages or currents than are available from a single module are required, modules must be connected into arrays. Energy technologies have a central role in social and economic development at all scales, from household and community to regional, national, and international. Among its welfare effects, energy is closely linked to environmental pollution and degradation, economic development, and quality of living [1].

Management of a solar array needs a reliable, expandable, flexible, cost efficient and self diagnosis system. All these specifications have to be taken into consideration in the design. The proposed control system consists of a Master controller (MC), which is responsible to control, transmit and receive data from each single tracker in the farm. A MC unit controls all solar tracking systems in the field and all these trackers are considered as being slaves for this master. Various modes of tracking have been taken into consideration namely, *Horizontal Single Axis Tracker (HAST), Vertical Single Axis Tracker (VSAT) and Dual Axis Trackers (DAT).* The user can choose any mode of tracking according to farm location and many other specified factors [2, 3]. The MC manages all these slaves via RS232 asynchronous communication protocol. This two wire network makes the system expandable via a software update only. To reduce the lost power in the transmission line and avoid lost data caused by the drop voltage across the data bus, transceivers have been added to the master and slaves circuits. The MC sends a serial sentence to the all the slaves in the farm. This sentence contains all the required data about the sun location and tracking mode. The slave controllers receive this sentence and drive the panel to the sun location. The slave controllers do not only send feedback information about the supply power by each one of them to the MC but also send a fault code for diagnosis purposes. (Figure 1) represents a block diagram of the main control unit in the farm with grid-tie inverter which makes the system ready for on-grid connection.

2. Tracking Mode Selection

The selection of tracker type is dependent on many factors including installation size, electric rates, government incentives, land constraints, latitude, and local weather. HSATs are typically used for large distributed generation projects and utility scale projects. The combination of energy improvement and lower product cost and lower installation complexity results in compelling economics in large deployments. In addition the strong afternoon performance is particularly desirable for large grid-tied photovoltaic systems so that production will match

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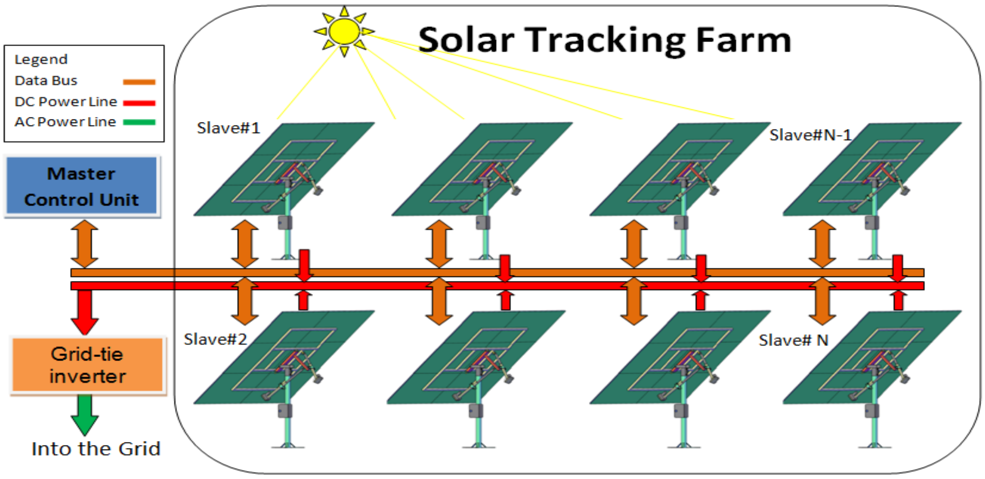
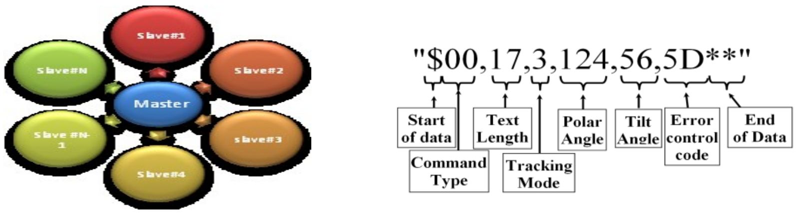


Figure 1. Master and Slave controller signal line diagram

the peak demand time. HSATs also add a substantial amount of productivity during the spring and summer seasons when the sun is high in the sky. The inherent robustness of their supporting structure and the simplicity of the mechanism also result in high reliability which keeps maintenance costs low. Since the panels are horizontal, they can be compactly placed on the axle tube without danger of self-shading and are also readily accessible for cleaning. A VSAT pivots only about a vertical axle, with the panels either vertical, at a fixed, adjustable, or tracked elevation angle. Such trackers with fixed or (seasonally) adjustable angles are suitable for high latitudes, where the apparent solar path is not especially high, but it leads to long days in summer, with the sun travelling through a long arc. The DATs are typically used in smaller residential installations and locations with very high government feed in tariffs [4].

3. Network Management

There are two main commands sent by the MC, namely shared and dedicated commands. The shared command is diffused from the MC into every single slave in the system as shown in the (Figure 2.a).These shared data received by all the slave systems display the used mode of tracking and sun location string followed by error control code as shown in (Figure 2-b). This command contains the following information:



(a) (b)

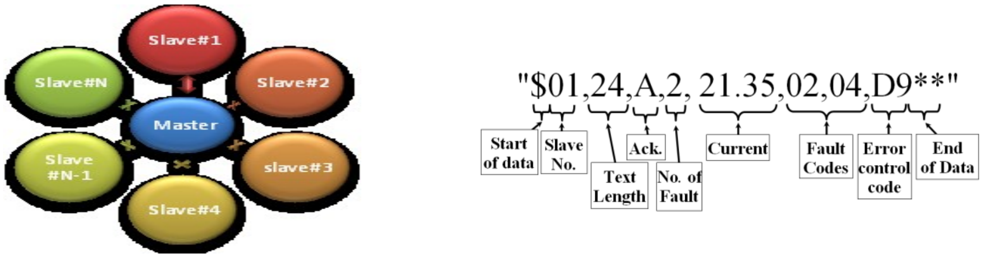
Figure 2. (a) Share Command signal flow diagram, (b) Master string data structure

- **Start of Data**: The data statement starts with "$" character. This character gives all the slave indication for start sending data.
- **Command Type**: Two characters are used as indication for command type and slave address at the same time. If the command type is "00", then it is a shared command, otherwise it is a slave address of the dedicated command.
- **Text Length**: Two characters are used to give an indication about the statement length.
- **Tracking Mode**: One character which refers to the selected tracking mode (1= HSAT, 2=VSAT, 3=DAT).
- **Polar Angle** [00-360]: Three characters to represent the polar angle are sent to all slaves periodically. This angle is determined based on the time of the day in case of DAT, HSAT or considered to be of fixed for VSAT.
- **Tilt Angle** [00-90]: Two characters to represent the tilt angle are sent to all slaves periodically. This angle is determined based on the day number in case of DAT, VSAT or considered to be of fixed for HSAT.
- **Error control code**: These two characters represent the XOR result of the sorted bytes shown in Table 1 as a check sum to control the error in the transmission. In the sender end, the checksum generator subdivides the data unit into equal segment of n bits (16 bits). These segments are added using ones complement arithmetic in such a way that the total sum is also n bits long. This sum is then complemented and appended at the end of the

original data unit as redundancy bits called the checksum field. The extended data unit is transmitted across the network. If the sum of the data segment is T, the checksum should be (–T). The receiver subdivides the data unit and adds all segments and complements the result. If the extended data unit is intact, the total value found by adding the data segment and the checksum field should be zero. If the result is not zero, the packet contains an error and the receiver rejects it [8].

- **End of data**: Two stars"**", to indicate the end of data transmission.

As for the dedicated command the MC sends these dedicated props periodically to all slaves in the farm, see (Figure 3.a). These props have no data, only "$" plus the slave address such as "$03". All the slaves in the farm will read this message but only one of them with the matching address will respond to it. The reply message by the slave controller contains the following information: slave number, message length, acknowledgment on the shared command, number of fault codes, the supply current by the system and list of error codes if any, see Table 2. This message, which is shown in (Figure 3.b), is followed by error control code (checksum) calculated as shown in Table 1.



(a) (b)

Figure 3. (a) Dedicated Command signal flow diagram, (b) Slave string data structure

Table 1. Checksum Calculations for the Master and Slave string data

Master String	**Hex**	Binary	**Binary**	**Slave String**	**Hex**	**Binary**	**Binary**
Command Type	00	0000	0000	Command Type	01	0000	0001
Text Length	17	0001	0111	Text Length	24	0010	0100
Tracking Mode & Polar Angle X00	31	0011	0001	Ack. & no. of faults	A2	1010	0010
Polar Angle 0XX	24	0010	0100	Current XX00	21	0010	0100
Tilt angle	56	0101	0110	Current 00XX	35	0011	0101
Sum	**C2**	**1010**	**0010**	Fault #1	02	0000	0010
Checksum	**5D**	**0101**	**1101**	Fault #2	04	0000	0100
				Sum	**26**	**0010**	**0110**
				Checksum	**D9**	**1101**	**1001**

Table 2. Fault diagnostics

Fault	**code**	**Fault Specifications**	**Possible reasons**
Over current1	01	Tilt actuator is over loaded	Over weight The panel is stuck
Over current2	02	Polar actuator is overloaded	Over weight The panel is stuck
Over heat	03	High temperature	Fan not working Blocked Ventilation holes
Freeze 1	04	Tilt actuator is not responding	For tilt or polar reed sensor fault Check reed sensor wires. Check the limit switch
Freeze 2	05	Polar actuator is not responding	Check the actuator itself Check for fault 01 or 02

4. Master and Slave Circuitry

The main goal of this design is simplicity and expandability. The MC circuit shown in Appendix A has the following sub circuits which complement the main controller (ATmega32):

- **Microcontroller auxiliary Circuits**: They include the reset push bottom to reset the MC, passive LC LPF to remove the ripple from the analogue signal, and 4x20 LCD screen characters for monitoring data. This screen displays many types of monitored data. The user has to change the displayed data by pressing Right-Left switches and the 4x4 matrix Keypad for entering data.
- **Temperature sensor** (LM35dz): Temperature monitoring is used for overheat protection, as the operating temperature plays a central role in the photovoltaic conversion process. Both the electrical efficiency and the power output of a PV module depend linearly on the operating temperature [5, 6, 7].
- **Power measurement**: This is built around measuring voltage and current in the main power line. The ADC (10 bits) in the MCU is scaled from 0-5 Volt. So, voltage and current conditioning circuits have to be used. Voltage conditioning circuit is used to scale down the voltage by 0.01. The current conditioning circuit consist of INA168 with shunt resistor ($R_{SH} = 0.0001\Omega$). This shunt resistor could be any piece of wire or specified length of the used cable. The output voltage of this circuit is directly proportional to the high side current according to ($V_O = I_S\ R_{SH}\ R_L/5k\Omega$). The circuit used R_L=50 kΩ, then $V_O = I_S$ *(0.0001 * 50k/5k) = 0.001 * I_S. R_{SH} is chosen of very low value to reduce the lost power. An extra Hall Effect sensor could be used for a high current low voltage system.
- **Real Time Controller (RTC):** It consists of a DS1307, back-up battery and 32768 Hz crystal. This controller manages all date and time data. It is initiated by the main controller via I2C communication protocol. This protocol is based on (SCL and SDL) signals, which allows communication between the MC and RTC.
- **Serial communication conditioning circuit**: The MC communicates with other slave controllers via RS232 for long distance in the field for that MAX232 has been used for conditioning the serial transferred signal between the master and slaves.
- **Driver circuit:** The slave controller drives three relays to enable power, choose motor and direction of motion. These relays are responsible for driving the required power to the actuator and reed sensor [9].

The MC can also manage directly a Buck-Boost converter via its built in PWM and the work is ongoing in this direction as in [10, 11].

The slave controller uses most of the above auxiliary circuits except the RTC because it does not need to calculate time, since the angles are sent directly by the MC.

5. Flow control

The full duplex communication system used here needs a flow control to manage the received signals from the multi slaves in the network. Shared command has no problem because all slaves receive the same message at the same time. The congestion happens when all the slaves try to send their specific information. To solve this problem the MC takes the responsibility to control the flow of data in the RX channel. The MC gives the permission for the slaves one by one to send their data. RX interrupt has been used to sense the channel for any data. When the listening controller detects signal on the RX line directly, it will read this signal then fetch the address after checking the validity of data. If the address belongs to it, then it replies directly a slave message including the acknowledgment.

Acknowledgment is used here to give an indication that the channel has problem. The MC will do nothing if it receives a non acknowledged signal from the slave and the reason is that the previously sent data are invalid since the time has been changed. Hence acknowledgment is just an indication for channel status. The periodic repetition of data gives the system good reliability by encoding the data as a repetition coding. (Figure 4) shows the flow control of the shared and dedicated signals.

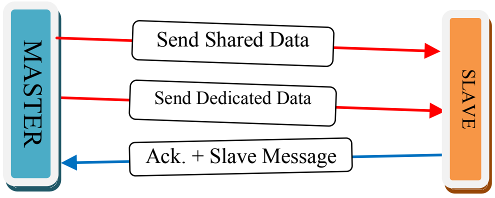


Figure 4. Flow control

6. System Intialization and Monitoring

The system can be initialized and run for one of the three mentioned modes. When the system starts running for first time a message shown in the screen asks to choose the required tracking mode, (see Figure A3 in Appendix A). To start the process, press 1 for HSAT, 2 for VSAT or 3 for DAT.

If HSAT mode was chosen, see (Figure A4), the user has to enter the fixed tilt angle as required, see (Figure A5). Time, Date and Latitude should be entered in the format shown in (Figure A 6-9). Now the system is initialized and ready for HSAT mode. The default mode (Figure A10) shows the system display of the time and date on the third row on the screen. The fourth row displays the Polar and Tilt Angles. Note that the Tilt angle will stay equal to the set value. If we need to know more about the system data, then we have to press Right (R) or Left (L) switch to change the displayed data. If R has been pressed, data in (Figure A11) will be displayed. This window displays astronomical values. It shows on the second row the latitude angle (LA) and declination angle (DA). On the third row the system displays the equation of time value (ET) and Delay (DL), which represents the time between the sunrise time and the start tracking time. The fourth row displays the start tracking angle (STTA) and stop tracking angle (SPTA). The next window (Figure A12) shows the power and temperature values. On the second row, the system displays the temperature in C^o or in F^o as required. The third row displays the main voltage and current, while the fourth row displays the total power supplied by the field.

For VSAT mode, we need to enter the required polar angle. (Figure A13, 14) show the display messages on the screen when VSAT is selected. Note that for this mode the polar angle on (Figure A15) is according to the selected value and not according to the instance value.

The last case is the DAT mode. In this mode the user does not need to force the tracker for tilt or polar angles. The MC calculates these angles and sends them directly to all the slaves in the field. (Figure A16) shows the displayed message when DAT mode is selected. Non forced angles can be easily recognized by comparing (Figure A17) with (Figure A10 and 15).

7. Conclusions

PV Solar tracker array systems make sense in urban areas with stable power supply. Building these systems needs a vast land area to avoid shading of panels. The vast area of the system needs to have a central control and data acquisition system to manage and monitor the produced power by each tracker and fault diagnosis. The proposed designed strategy followed in this paper offers a smart control and monitoring system for each tracker in this array beside the high reliability, expandability and cost effectiveness of the system. The new approach in network protocol allows the master and slaves to communicate with minimum number of wires and minimum circuit complexity as the proposed design needs no channel sensing circuitry. Expansion of the array needs only a software update to the slaves address. No slave select (SS) wire needs to be added as in Serial Peripheral Interface (SPI). The master controller duties in managing the data flow control is regarded as a good channel multi access technique.

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Appendix A: System Circuitry and Monitoring

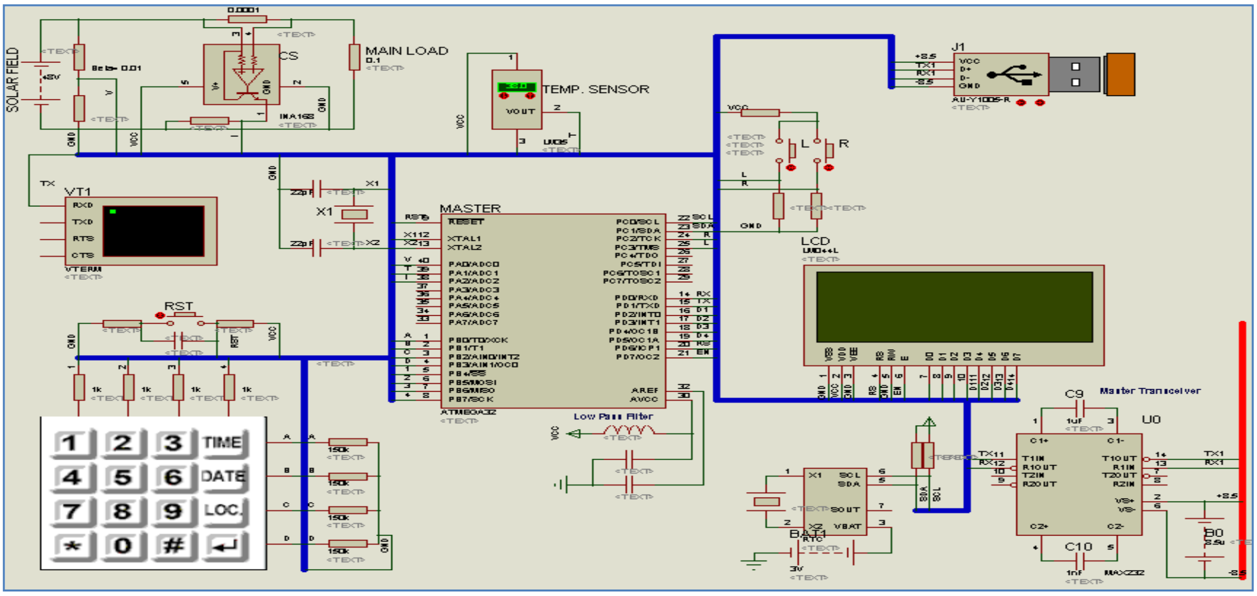

Figure A.1 Master Controller circuitry

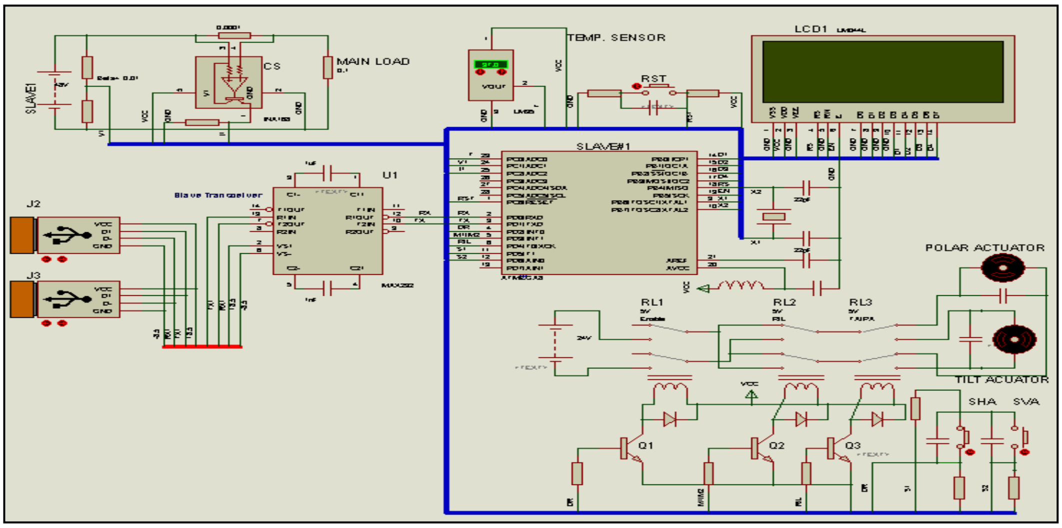

Figure A.2 Slave Controller circuitry

Figure A.3

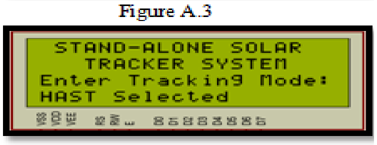

Figure A.4

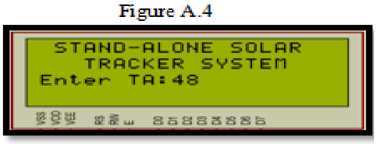

Figure A.5

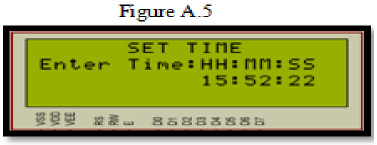

Figure A.6

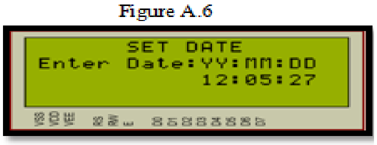

Figure A.7

Figure A.8

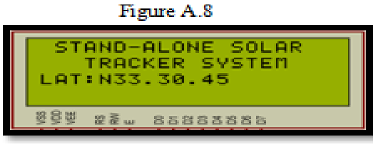

Figure A.9

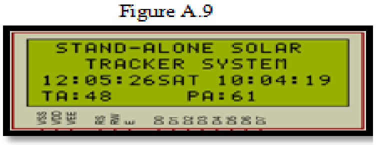

Figure A.10

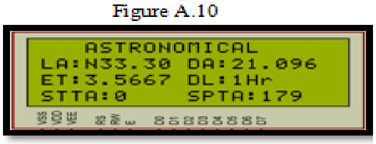

Figure A.11

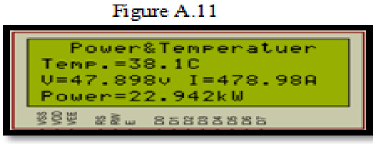

Figure A.12

Figure A.13

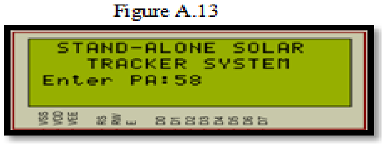

Figure A.14

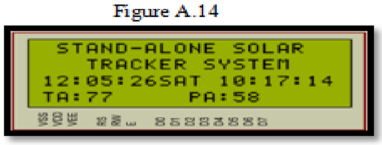

Figure A.15

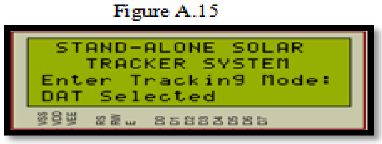

Figure A.16

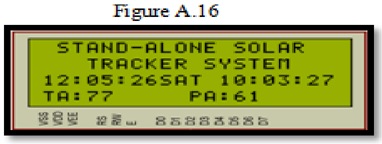

Figure A.17