Chapter 31

Digital Control of Pulsed Magnetron Modulator

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The control system described here is designed for a Line type magnetron modulator which uses CCPS to charge the pulse forming network. The modulator needs to be operated in two modes, Single Energy or voltage mode in which every pulse will be of same voltage. The second mode will be a Dual Energy or voltage mode in which one pulse will be of V1 and the other pulse will be of V2 Voltage. These voltage levels can be set from a remote HMI. The block diagram of the modulator is shown in Fig. 31.1.

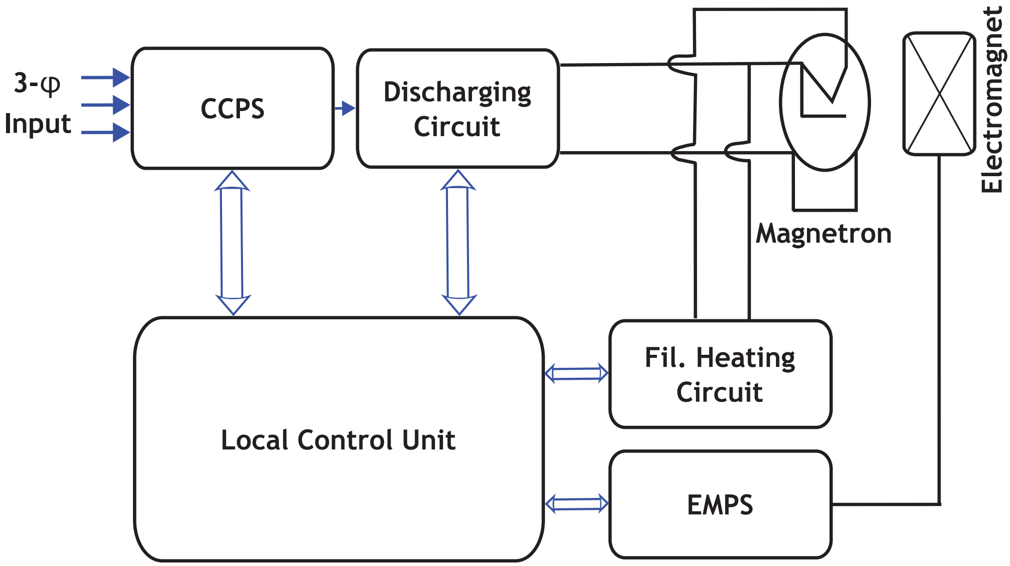

Figure 31.1: Block Diagram of CCPS based Magnetron Modulator.

Main functions of local Control system:

a. Provide interface for remote operation of the modulator.
b. Generate the magnetron output pulse in synchronization with the external reference pulse.
c. Generate required pulses for charging and discharging circuits.
d. Monitor fast and slow interlocks for human and machine safety.
e. Arc fault monitoring and counting.
f. Magnetron filament heating control based on average power.
g. Monitoring of Electromagnet supply current.

31.1 System Description

The control scheme for modulator is shown in Fig. 31.2. It consists of a PLC controller with associated IO Cards, MCU Board with associated signal conditioning Boards and remote HMI. The remote HMI and MCU board communicates with Modbus RTU protocol (Link 1). For Link 1 Remote HMI is MASTER and MCU is SLAVE. The MCU Board and PLC are also communicates Modbus RTU protocol (Link 2). For Link 2 MCU is MASTER and PLC is SLAVE. The fast signals between modulator and MCU board are first converted in to optical from electrical at source and then converted back to electrical at receiving end. Optical transmitter and receivers are used for this purpose. Slow signals (Digital inputs, Digital

Outputs, Analog inputs, Analog Outputs) from modulator are monitored and controlled by PLC.

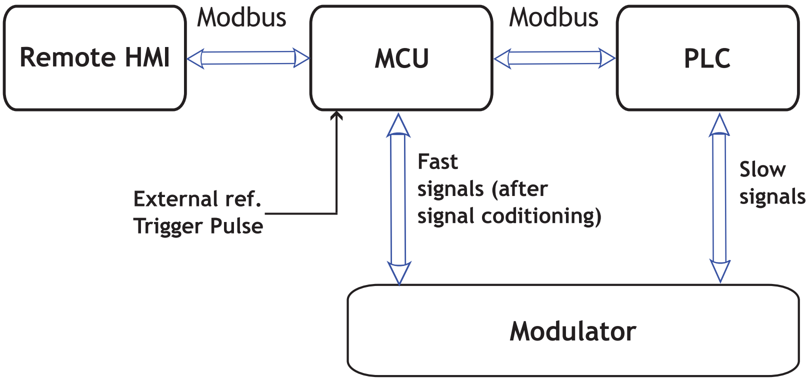

Figure 31.2: Local control scheme.

The timing diagram of operation of the modulator is shown in Fig. 31.3. As shown in figure at the rising edge of external reference pulse a Thyratron trigger pulse of around 2 μs to trigger the main Thyratron in discharging circuit is generated. After turn on of Thyratron the HV pulse will get generated and RF output from magnetron will be generated. After a delay of around 200 μs from rising edgue of external pulse Charging cycle is started. During charging two pulses of around 6 μs each and frequency of around 40 kHz are generated to switch on and off the CCPS full bridge IGBTs. Care has been taken that these two pulses will never be on at the same time. Voltage feedback from CCPS is monitored and compared continuously with the set point during charging period to stop the charging once set value is reached. At the end of charging cycle a pulse of around 100 μs pulse width is generated. At the start of charging cycle a timer of 3.3 ms is started and at the end of this timer, status of charging is checked if charging is not complete then charging fault will be generated else no fault will be generated. The timing diagram also shows the CCPS output voltage, as can be seen from the diagram the voltage goes to zero once the Thyratron is on and builds up with a constant rate when charging is on up to the set value.

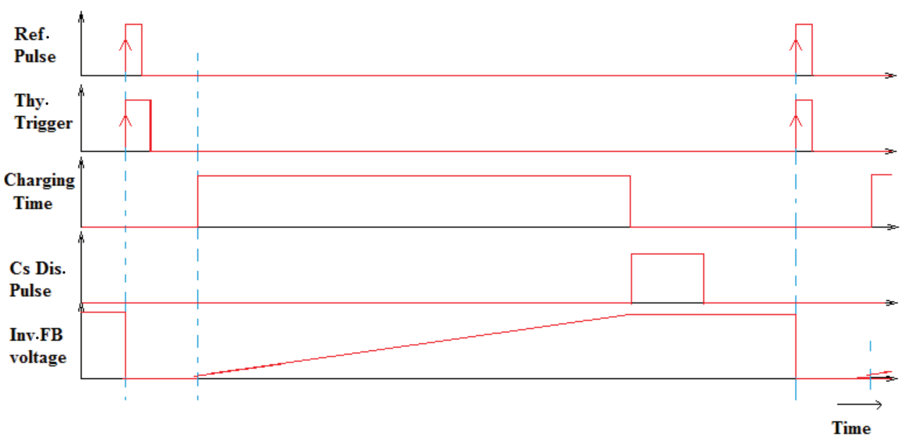

Figure 31.3: Pulse Timing Diagram.

Details of the output pulses generated by control system in synchronization with the external reference trigger pulse:

i. Thyratron trigger pulse (0-2 μs) : Generated at the rising edge of the external pulse, pulse width is adjustable from remote HMI.
ii. Charging IGBT Pulses: Generation of Trigger pulses for CCPS full bridge IGBTs, Two pulse are generated with adjustable pulse width of 6-8 μs and adjustable frequency of each pulse from 35 kHz to 40 kHz.
iii. Cs Discharge Pulse (100-200 μs): Generated at the end of charging, pulse width can be adjusted from remote HMI.

The main circuit boards and devices used in this control unit are listed below:

1. Microcontroller unit (MCU) interface circuit board
2. Programmable logic controller with I/O Cards
3. Remote HMI
4. CCPS IGBT Driver Board
5. Thyratron Trigger Board
6. Inverter Feedback Board
7. Arc Detection Board
8. Average Power Measurement Board

Details of above listed devices and boards are as given below.

31.1.1 MCU Interface Circuit Board

The interface board has been designed to connect three types of daughter boards to it. It has communication interface with that two RS232 field devices can be connected to onboard daughter board with UART. It has required driver ICs to drive the Optical transmitters. The details of daughter boards connected to the interface board are given below.

31.1.2 TI Make LAUNCHXL-F28379D Development Board

The MCU used in the design is LAUNCHXL-F28379D which uses Texas Instruments (TI) TMS 320F28379D controller. F28379D is a dual core controller. Each core is identical with access to its own local RAM and flash memory, as well as globally shared RAM memory. Sharing information between the two CPU cores is accomplished with an Inter-Processor Communications (IPC) module. Additionally, each core shares access to a common set of highly integrated analog and control peripherals, providing a complete solution for demanding real-time high-performance signal processing application.

31.1.3 Optical Receiver Board

This board is used to receive optical field signals and has eight number of channels. Two such boards can be connected to interface board and hence has capacity of 16 numbers of optical inputs.

31.1.4 Optical Transmitter Board

This Board is used to transmit control signals to field in optical form and has eight channels. Two such boards can be connected to interface boards and hence has capacity of 16 numbers of optical outputs.

31.1.5 Programmable Logic Controller with I/O Cards

The PLC used in design is Schneider Electric make TWDLMDA20DRT model. This model has 12 Digital inputs, 6 Relay outputs and 2 Source Transistor (0.3 A) outputs. The PLC system has one digital output module, Analog input module, Analog I/O module and a communication module.
The PLC unit monitors slow interlocks like water flow, door switch, 3 phase UV/OV, emergency fault, filament UV and timer, temperature interlocks etc. PLC also monitors the electromagnet current feedback and generates fault if the current is not in specified limit. The average electrical power input to the magnetron is measured and the filament power of the magnetron is adjusted as per the data given by magnetron manufacturer. PLC unit receives commands from MCU board and provides status of field signals to MCU board on a Modbus RTU link.

31.1.6 Remote HMI

The operational requirement from the system is that the modulator is to be placed in an inaccessible area during operation, hence the local control panel or interface is not required. Instead the local control unit has provision for connecting a Remote HMI on Modbus and control it from the centralized control room. List of parameters which are controllable from HMI are listed in table 31.1. The status of all the fast and slow interlocks, plc communication, average power value, electromagnet current etc are also be monitored from remote HMI.

Table 31.1: List of control parameters from remote HMI.

Sr. No.	**Control Parameter**	**Function**
1	Modulator ON/OFF	3 phase supply switched ON/OFF, Filament heating of magnetron, Thyratron will be started
2	V1 SET (kV)	Set point 1 for CCPS (HE mode)
3	V2 SET (kV)	Set point 2 for CCPS (LE mode)
4	Thyratron trigger pulse width	Pulse width is adjustable from 0 μs to 2 μs
5	Cs discharge trigger pulse width	Trigger for Cs discharge circuit, pulse width is adjustable from 100 μs to 200 μs
6	Charging fault window width	Maximum charging time allowed per pulse, adjustable from 3 ms to 3.3 ms.
7	ARC Limit	Adjustable from 1-16 no of arcs, set number of consecutive arcs will be counted before generating arc fault
8	Charging Frequency (kHz)	CCPS Full bridge IGBT switching frequency, adjustable from 70 kHz to 80 kHz
9	Delay before charging	Delay after magnetron pulse to start the charging, adjustable from 100 μs to 200 μs.
10	IGBT on time	CCPS full bridge IGBT on time, adjustable from 6 μs to 7 μs
11	RESET	Used to reset all the latched faults in MCU as well as PLC

31.1.7 IGBT Driver Board

This is a driver circuit for CCPS IGBTs. The board receives two IGBT trigger pulses from MCU board in optical form. Depending on them it generates trigger pulse for four IGBTs in full bridge configuration. This board uses two SCALE 2 driver modules (2SC0106T). The board generates fault in case of short circuit and passes that information to MCU board in form of optical status signal.

31.1.8 Thyratron Trigger Board

Receives optical trigger from MCU board and based on that generates gate pulse for IGBT used in the Thyratron trigger circuit.

31.1.9 Inverter Feedback Board

On this board V1 and V2 set signals generated by analog module of PLC and feedback signal from inverter are compared and two digital optical signals are generated and transmitted to MCU Board. Depending on status of these two inputs and mode of operation of modulator, MCU decides the point to stop the charging. The Inverter feedback board also generates a fault signal incase the feedback cable is open at inverter end or board end.

31.1.10 ARC Detection Board

This board has a 30 turn CT which measures current in case of ARC. Output of this CT is used to drive an optical transmitter, in case of arc the transmitter generates light. The same is detected on MCU board, consecutive arcs are counted to generate fault.

31.2 Summary

The Digital control using TI MCU comprising signal conditioning boards, controller interface and communication boards, PLC and HMI has been designed. The control system is implemented in a 19 inch mountable 4U sub-rack is implemented and installed in a modulator rack. The modulator is tested on a resistive load up to 20 kV CCPS voltage and 40 kV pulse voltage. The ARC fault testing is also completed. The modulator is operated from a remote HMI.

Questionnaire

Q1. What are the advantages of using digital control instead of conventional IC based control system?

Q2. Which functional block of the micro controller unit is used to generate the trigger pulses?

Q3. How the communication between MCU board and PLC works?

Q4. What are consecutive ARCs and how they are detected?

Q5. What is the difference between fast and slow interlocks?

Q6. What are the challenges in the design of control for pulse modulators and how are they addressed in this design?

Suggestions for Further Reading

a) [149–152]