AC System Monitoring Device

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Outline

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Problem Background for the AC System Monitoring Device

- Alternating current (AC) monitoring device is a device to monitor voltages, current, power factor, and other AC power characteristics
- Primarily used in power transmission monitoring and power system protection
- Key part of the smart grid
  - Reliability
  - Networking Capability
- Power Factor Control

Problem Statement for the AC System Monitoring Device

- View AC power characteristics
  - AC voltage
  - AC current
  - AC power factor
- Power Factor control
  - Switching capacitors

Constraints for the AC System Monitoring Device

- Must be a digital system
- Must be secure
  - Limiting unauthorized access and control
- Must operate from 120 to 250 volt AC systems
  - ECE Power lab limits
- Must be safe using device
  - To the user

Scope for the AC System Monitoring Device

Scope	Out of Scope
Monitor AC Voltage	Monitor DC Voltage
Monitor AC Current	Monitor DC Current
Calculate Power Factor	Calculate Current Differential
Power Factor Correction	Transformer Protection
Single-Phase AC Systems	Three-Phase AC Systems
Display Interface	Network Interface
Digital Processing	Electrical Mechanical Controls

Functional Requirements

- Shall monitor AC voltage
- Shall monitor AC current
- Shall monitor AC power factor
- Shall control power factor

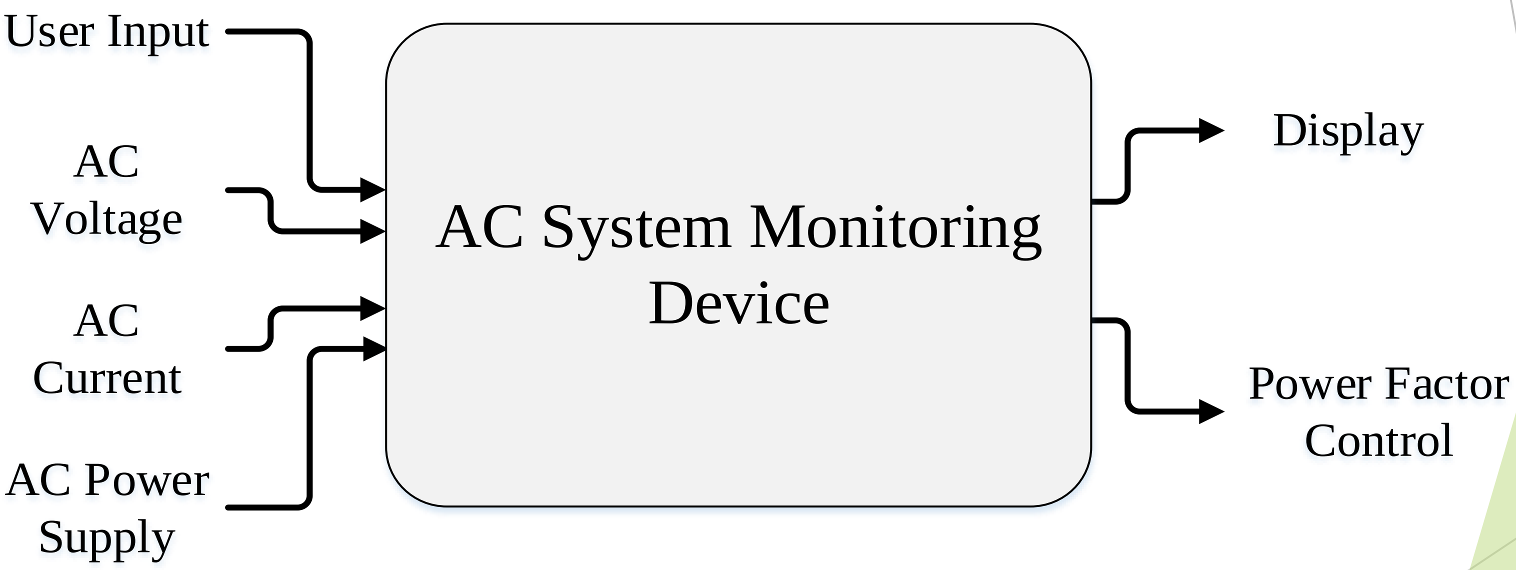
Metrics for Functional Requirements

	Max	Min	Tolerance
Voltage Range	250 V	100 V	±15%
Current Range	5A	0 A	±15%
Power Factor Calculation	1.0	0.3	±15%
Control Power Factor	N/A	1 Switch Control	N/A

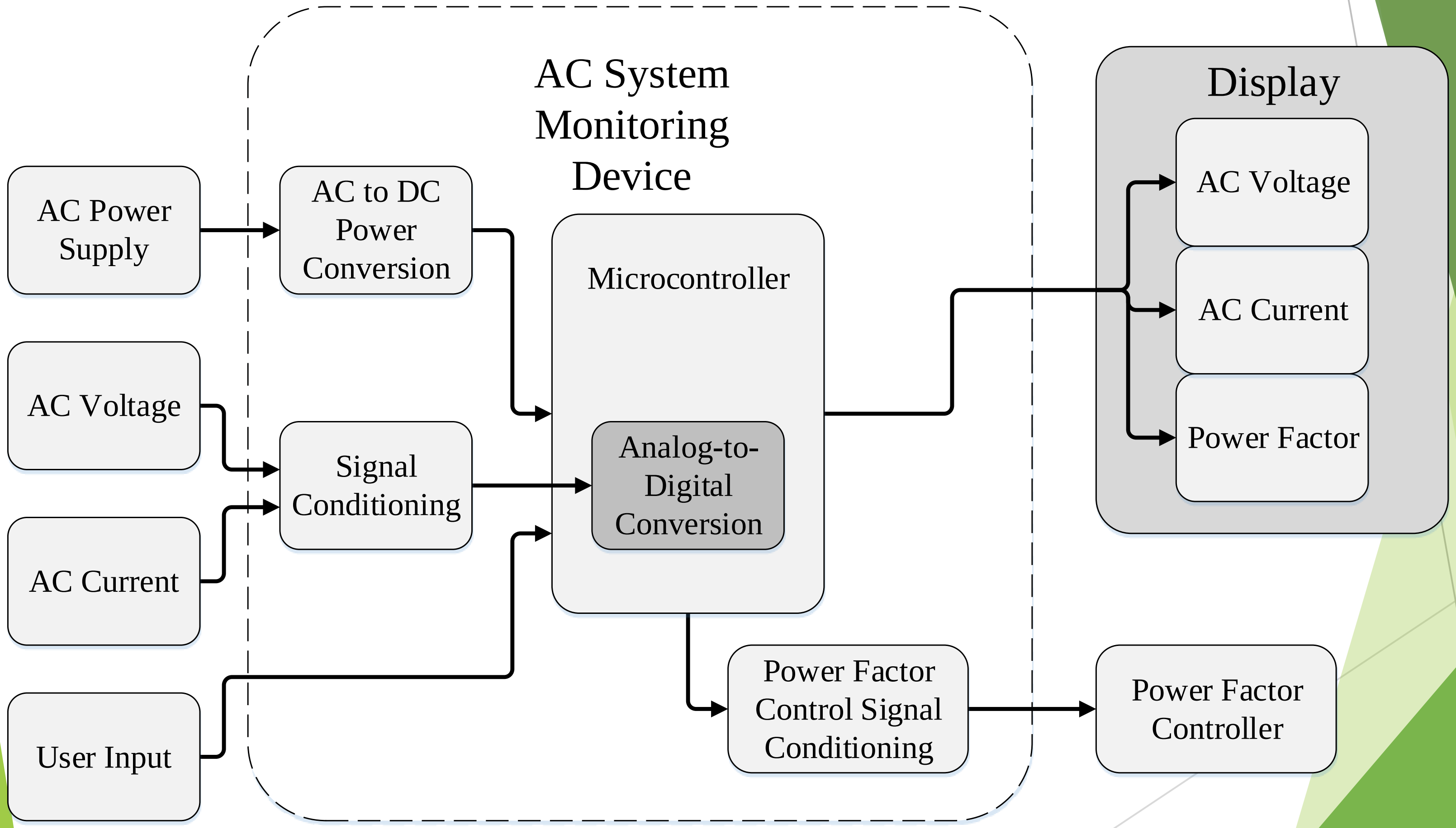
Nonfunctional requirements

- AC monitoring device should be reliable
  - Stable microcontroller operations
  - Accurate AC power characteristic outputs
- AC monitoring device should be usable
  - User experience with the device

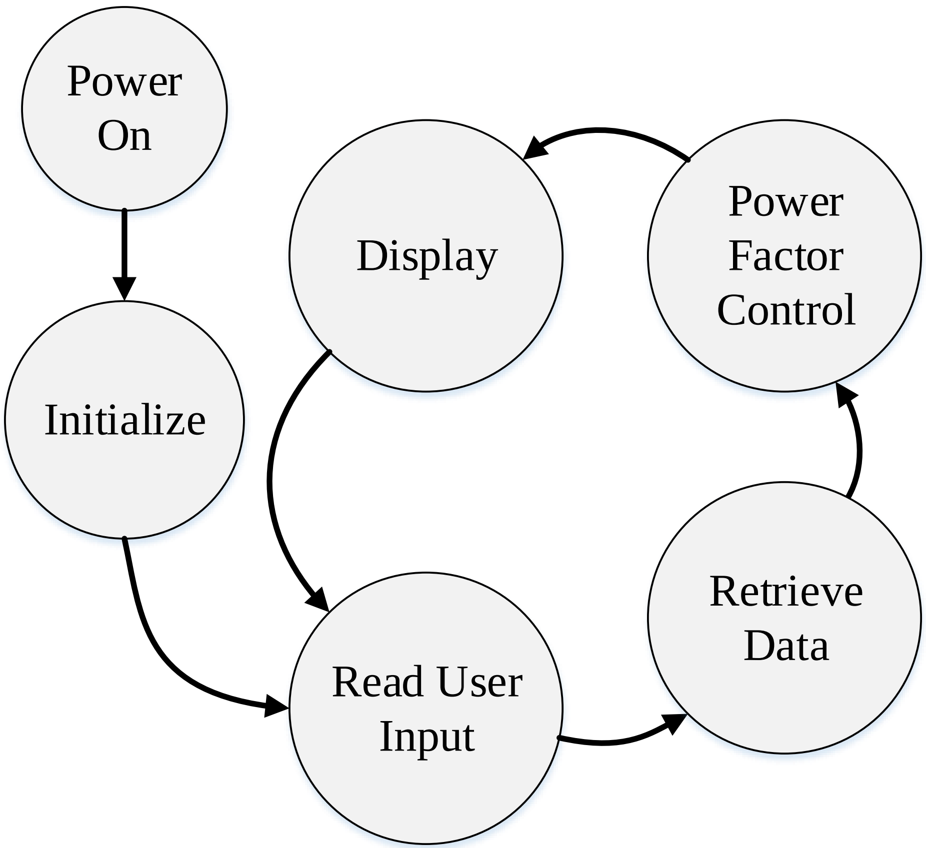
High Level System Block Diagram of the AC System Monitoring Device



Subsystem Block Diagram of the AC System Monitoring Device



State Diagram of the AC System Monitoring Device

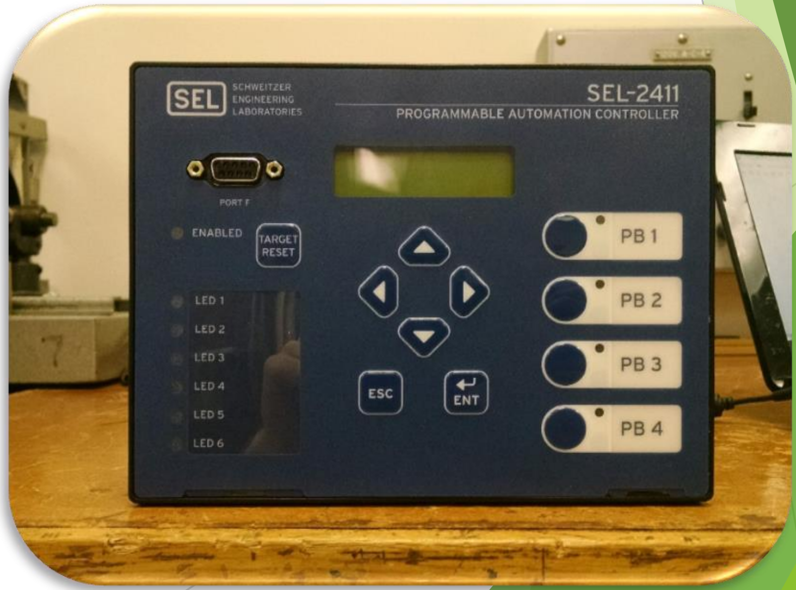


Design Approach

- Morphological Chart
  - Functional Requirements
  - Different means
- Numerical Evaluation
  - Different means
  - Nonfunctional requirement metrics
  - Constraints
- Personal Experience
  - C Programming with Atmel
  - Relay control from Ameren Internship

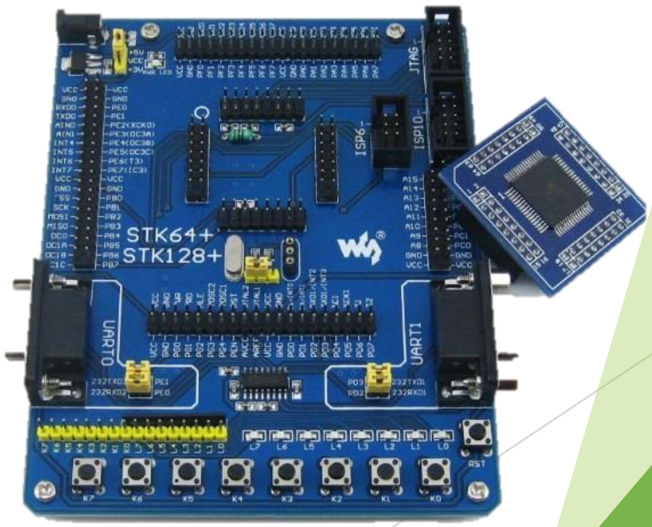
Proposed Solution

- Use a programmable logic controller (PLC)
- Schweitzer Engineering Laboratories (SEL) Automation Controller (SEL-2411)
- AC Voltage and Current I/O Card
- Digital I/O Card to control power factor
- Used in power distribution control at Ameren
- 615V 600uF Capacitors



Alternative Solution

- ATmega128A Development Board
- HITACHI HD44780U LCD Display
- Hall Effect Sensor
- Full wave bridge rectifier
- Transformer 117Vac to 24Vac
- 615V 600uF Capacitor
- 120V 120A Power-transistor



Testing

- Use equipment from power lab to compare outputs of the device
  - Verify AC voltage and current displayed
  - Verify AC power factor displayed
- Test power factor correction
  - Run a motor varying the load to change the power factor
  - Connect device to control capacitor
  - Verify operation of device to correct power factor
- Run device for periods of time to test reliability
- Usability testing through surveying

Economic Analysis of the AC System Monitoring Device

- SEL-2411 Controller
  - Premium price
  - Industrial grade
  - Customizable
  - 10 Year warranty
  - Donated from SEL
  - Free software to program
- ECE Power Lab Equipment
  - 3-Phase AC Motor
  - 615V 600uF Capacitors

Proposed Solution Parts

Parts	Quantity	Price
SEL-2411 Automation Controller (Base Price)	1	$ 950
SEL-2411 Expansion I/O Cards	5	$ 100
	Total =	$1450

Milestones

1. Research and Design
   - Components
   - Circuit Design
   - Programming
2. Primary Stage of Functional Components
   - AC Voltage Measurement
   - AC Current Measurement
   - User Interface Control
3. Secondary Stage of Functional Components
   - Power Factor Calculation
4. Third Stage of Functional Components
   - Power Factor Control
5. Final Overall System Testing

PERT Chart

Critical Path	Non-Critical

PERT Chart	Estimated Days to Complete	Forward Pass		Backwards Pass		Free Float
		Early Start	Early Finish	Late Start	Late Finish	
Component Research	8.2	0.0	8.2	4.0	12.2	0.00
Circuit Design	16.7	8.2	24.9	12.2	28.9	0.00
Program Design	7.3	24.9	32.2	28.9	36.2	0.00
Monitor AC Voltage Build	12.0	32.2	44.2	36.2	48.2	0.00
Monitor AC Voltage Testing	6.0	44.2	50.2	48.2	54.2	4.00
Monitor AC Current Build	16.0	32.2	48.2	32.2	48.2	0.00
Monitor AC Current Testing	6.0	48.2	54.2	48.2	54.2	0.00
Calculate Power Factor Build	16.7	54.2	70.9	54.2	70.9	0.00
Calculate Power Factor Testing	12.0	70.9	82.9	70.9	82.9	0.00
Power Factor Control Control Build	8.3	82.9	91.2	82.9	91.2	0.00
Power Factor Control Testing	6.0	91.2	97.2	91.2	97.2	0.00
User Interface Control Build	8.1	32.2	40.3	81.1	89.2	0.00
User Interface Control Testing	8.0	40.3	48.3	89.2	97.2	48.89
Overall System Testing	9.3	97.2	106.6	97.2	106.6	0.00

Preliminary Schedule

Activity	Start	End
Component Research	08/26/15	09/24/15
Circuit Design	09/24/15	10/15/15
Program Design	10/15/15	10/31/15
Monitor AC Voltage Build	10/29/15	11/26/15
Monitor AC Voltage Testing	11/26/15	12/09/15
Monitor AC Current Build	10/29/15	11/26/15
Monitor AC Current Testing	11/26/15	12/09/15
Calculate Power Factor Build	12/09/15	02/10/16
Calculate Power Factor Testing	02/10/16	02/25/16
Power Factor Control Build	10/29/15	02/17/16
Power Factor Control Testing	02/17/16	02/25/16
User Interface Control Build	10/29/15	02/25/16
User Interface Control Testing	02/25/16	03/09/16
Overall System Testing	03/09/16	03/24/16

Societal & Environmental Impacts

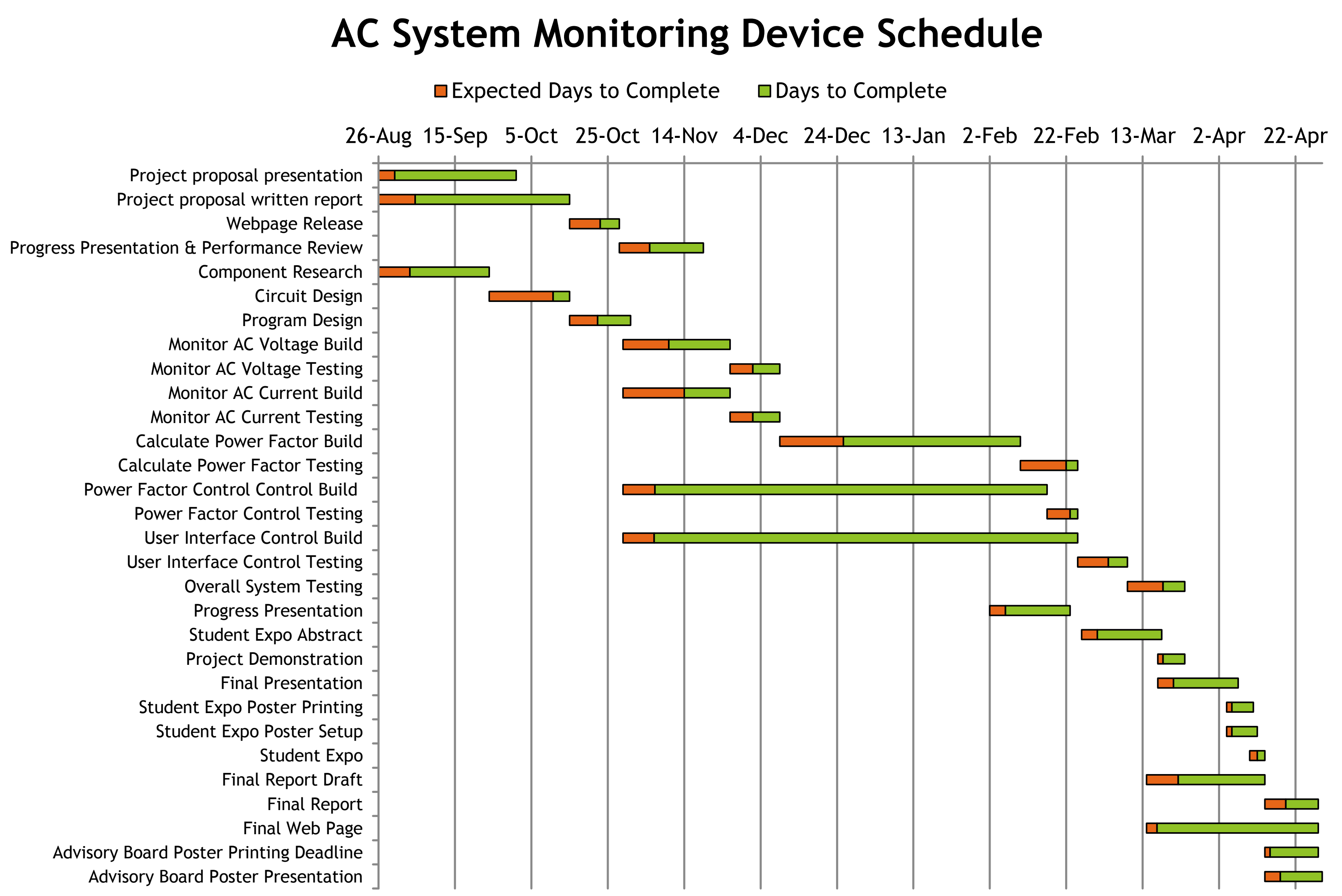
- More Reliable
- Energy Conservation
- Less periodic maintenance
- Safer

Summary & Conclusions

- Monitoring of 120/250 Vac systems and power factor correction.
- Proposed and Alternative solutions
- Testing device
- Economic analysis
- Preliminary Schedule
- Societal and environmental impacts

Q & A

Detailed Gantt Chart



Metrics for Reliability Nonfunctional Requirements

Performance Index	
MTBF (Mins)	Points
480 >	10
360	7.5
240	5
120	2.5
< 60	0

Metrics for Usability Nonfunctional Requirements

Objective: The AC System Monitoring Device should be usable

Units: User subjective satisfaction

Metric: Points will be assigned based on the following scale

- User is very satisfied with all key functions of the device - 10 points
- User is satisfied with key functions of the device missing other functionality - 5 points
- User is not satisfied with all the key functions of the device – 0 Points

Morphological Chart

Functions	Means			
Monitor AC Voltage	Full wave bridge rectifier to DC voltage signal	Dual half wave rectifier to DC voltage signal	Center tap bridge rectifier to DC voltage signal	Industrial PLC
Monitor AC Current	Hall effect sensor	Industrial PLC		
Monitor Power Factor	Use data from AC voltage and AC current conversion with internal calculations done by microcontroller	Look-up table to calculate the power factor from the AC voltage and AC current	Industrial PLC	
Power Factor Control	Output control from the same microcontroller that performs calculations. Power amplifiers will be used to interface with the AC system.	Output control from separate microcontroller that receives voltage and current data will perform programmable logical operations. Power amplifiers will be used to interface with the AC system.	Industrial PLC	

Numerical Evaluation

Design objectives (O) & constraints (C)	Design 1	Design 2				Design 3			
	Industrial PLC	Full wave bridge rectifier	Hall Effect sensor	Look-up table	Output logic from same microcontroller	Full wave bridge rectifier	Hall Effect sensor	Internal calculations	Output logic from same microcontroller
O: Reliable	10	7.5	10	7.5	10	7.5	10	7.5	5
O: Usable	10		10		10		10		5
C: Safe	X		X				X		
C: Secure	X			X	X			X	X
C: Operate up to 250V	X	X	X			X	X		
C: Digital system	X			X	X			X	X

Alternative Solution Parts

Parts	Quantity	Price
Atmel ATmega128A development board	1	$ 58.79
HITACHI HD44780U LCD display	1	$ 14.99
117vac to 24vac Power Transformer	2	$ 47.90
12A 600V full wave bridge rectifier	2	$ 14.80
615V 600uF capacitors	2	$ 14.86
Hall effect sensor (SparkFun ACS712)	1	$ 7.95
120V 120A Power-transistor (IPP041N12N3 G)	5	$ 13.30
	Total =	$182.59