ME/ESE 4470
Wind and Tidal Power
Energy Storage

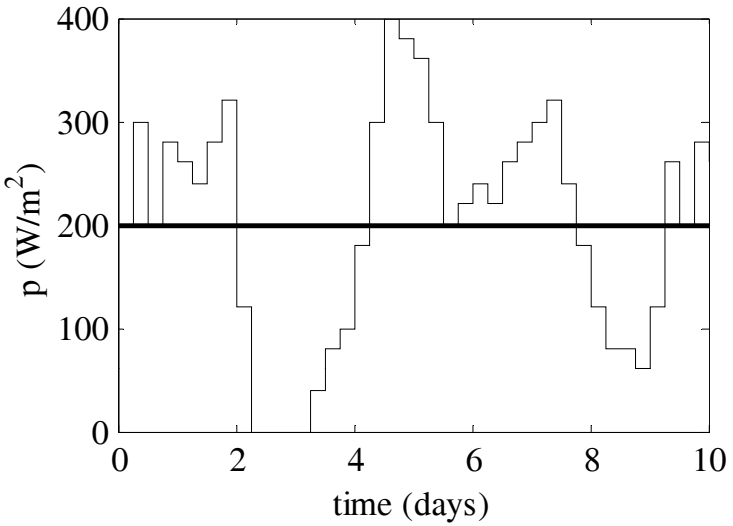
Energy Storage

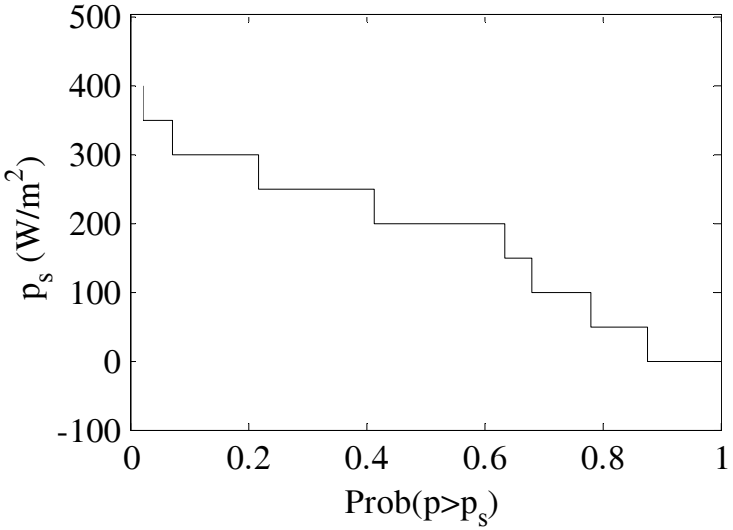
A. Introduction

Energy Storage

A. Introduction

   1. Renewable Energy Sources without Storage

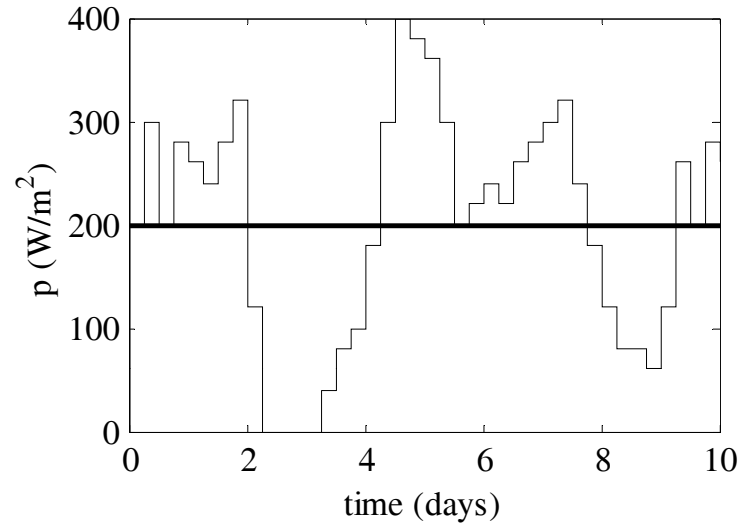


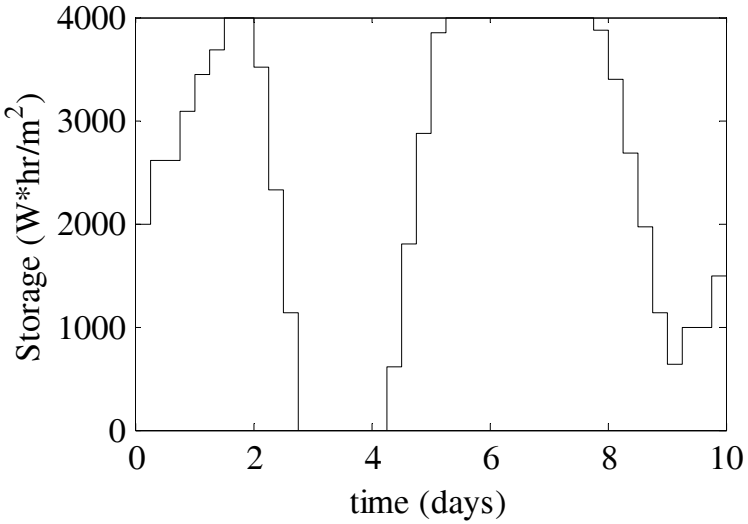


Energy Storage

A. Introduction

   2. Renewable Energy Sources with Storage

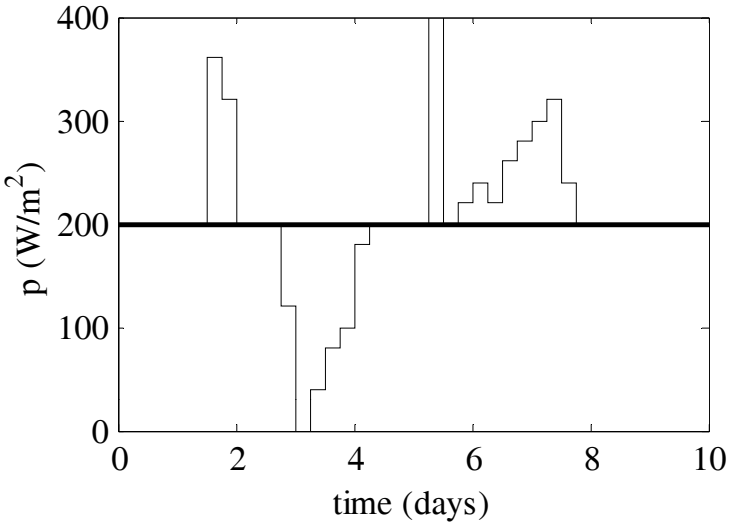


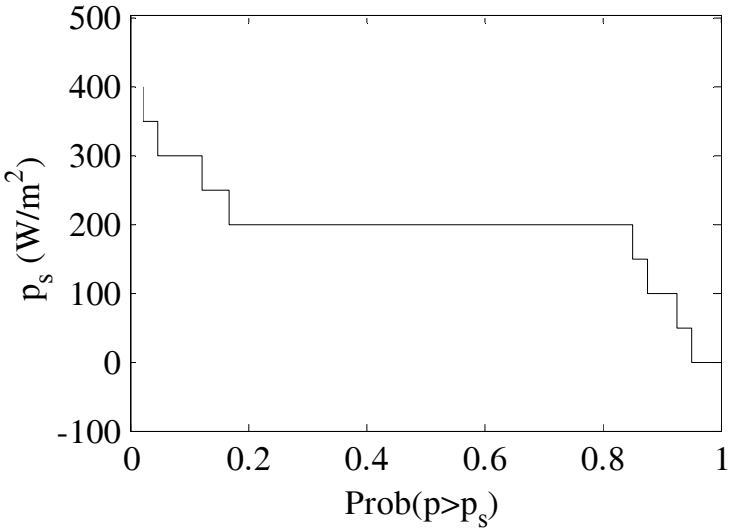


Energy Storage

A. Introduction

   2. Renewable Energy Sources with Storage

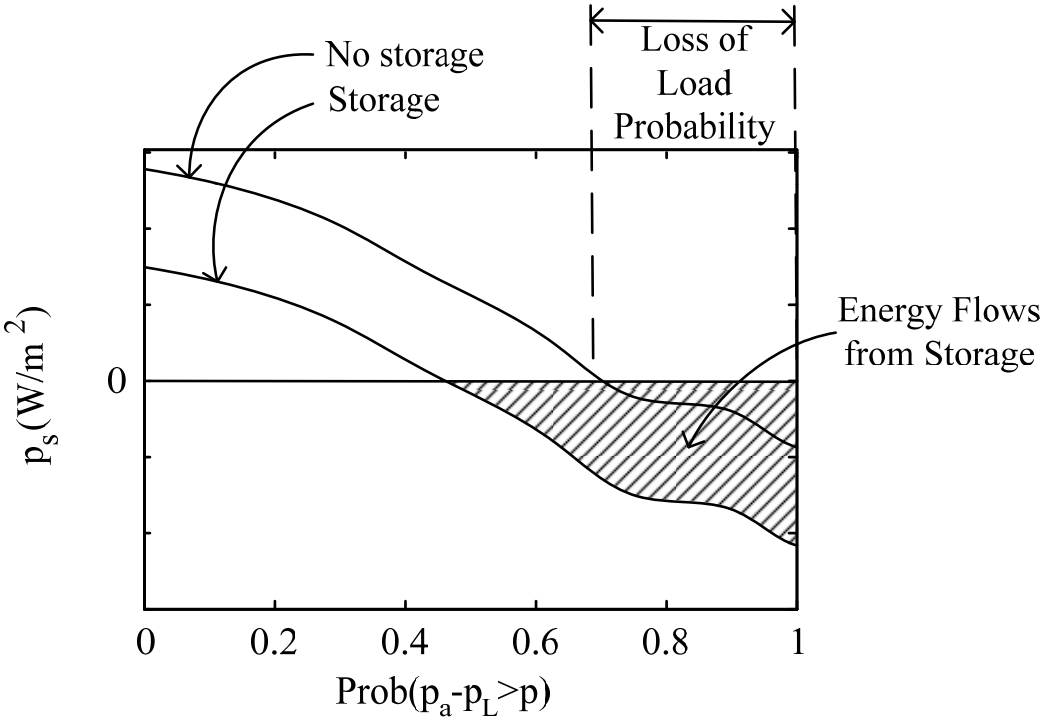




Energy Storage

A. Introduction

3. Load Management

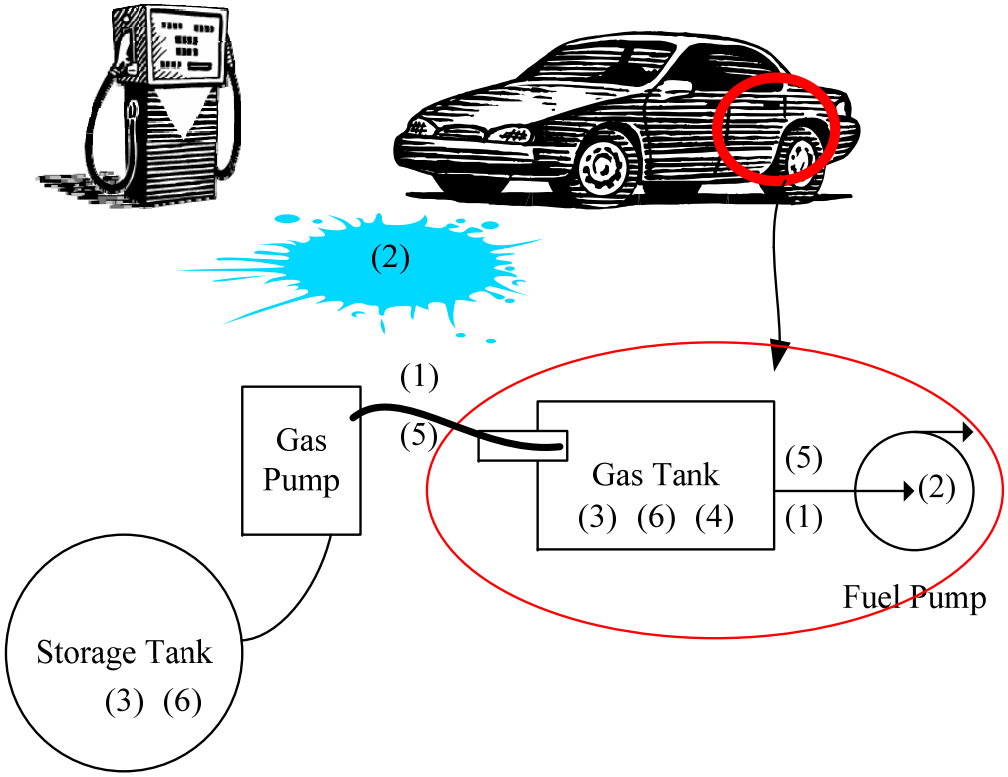


Energy Storage

B. Storage System Features

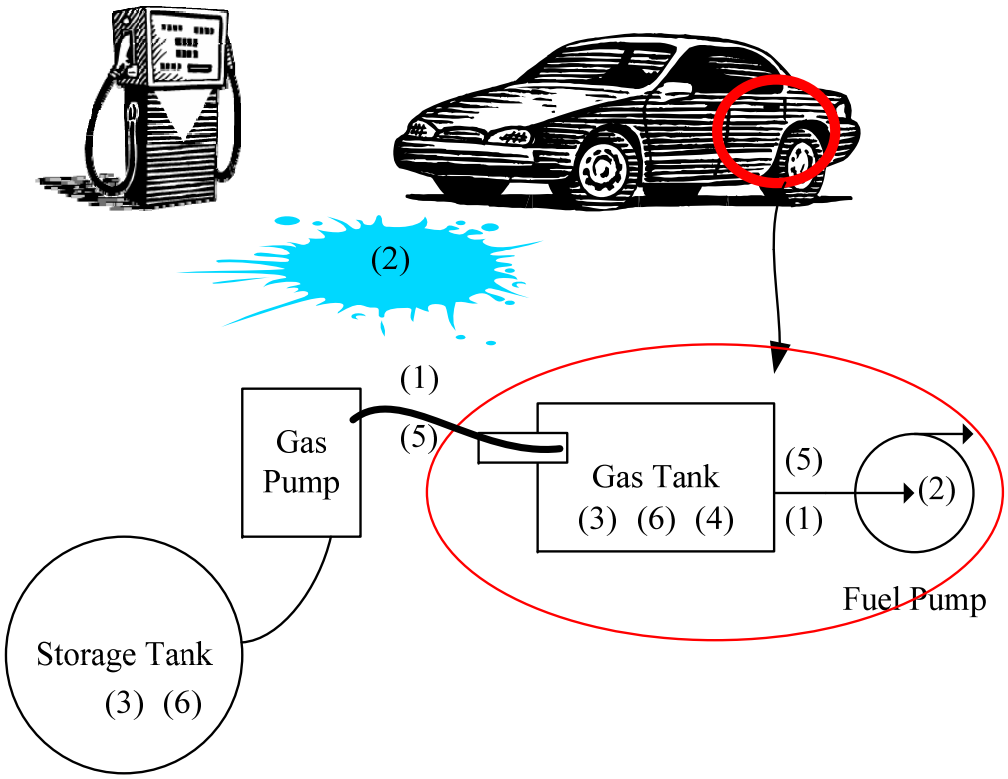
Energy Storage

B. Storage System Features



Energy Storage

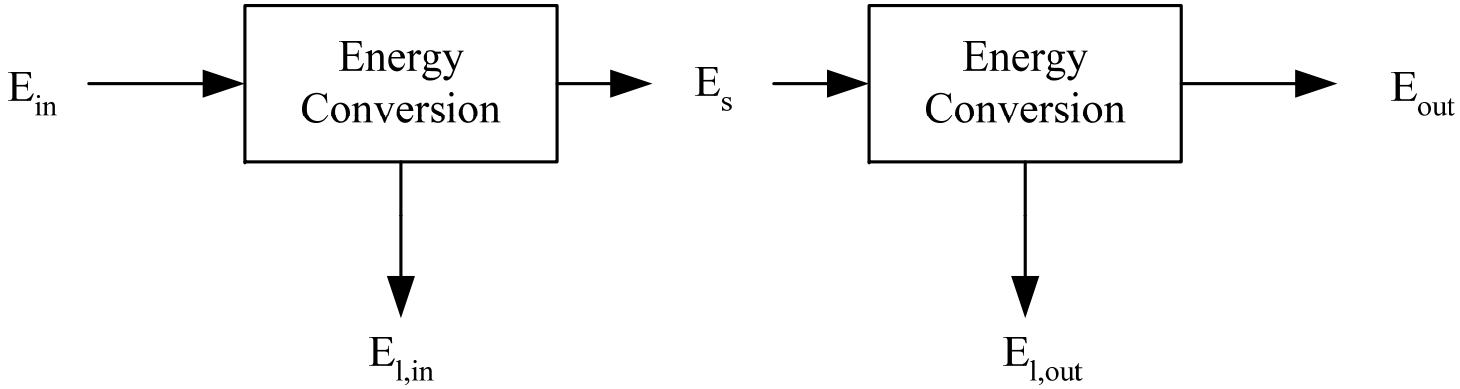
B. Storage System Features



Energy Storage

C. Energy Storage Performance Metrics

1. Efficiency



Energy Storage

C. Energy Storage Performance Metrics

   2. Energy and Power Density

Energy Storage

C. Energy Storage Performance Metrics

   2. Energy and Power Density

Energy Storage

C. Energy Storage Performance Metrics

2. Energy and Power Density

Storage Form Storage Form	e_m kJ/kg	e_V MJ/m^3	cycle η
Crude Oil	42,000	37,000	
Coal	32,000	42,000	
Hydrogen Gas	120,000	10	0.4-0.6
Hydrogen Liquid	120,000	8700	
Hydrogen Metal Hydride	2000-9000	5000-15,000	
Ethanol	28,000	22,000	
Methanol	21,000	17,000	
Water 40-100° C	250	250	
Rocks 40-100° C	40-50	100-140	
Iron 40-100° C	30	230	

Energy Storage

C. Energy Storage Performance Metrics

2. Energy and Power Density

Storage Form Storage Form	e_m kJ/kg	e_V MJ/m^3	cycle η
Rocks 200-400° C	160	430	
Iron 200-400° C	100	800	
Salts (Phase Change)	>300	>300	
Pumped Hydro - 100 m head	1	1	0.65-0.80
Compressed Air		15	0.40-0.50
Flywheels, Steel	30-120	240-950	
Flywheels, Advanced	>200	>100	$\sim$ 0.95
Lead-Acid Battery	40-140	100-900	0.7-0.8
Nickel-Cadmium	350	350	
Advanced Battery	>400	>400	

Energy Storage

D. Forms of Energy Storage

1. Mechanical Storage

a) Gravitational Storage

Energy Storage

D. Forms of Energy Storage

1. Mechanical Storage

b) Elastic Storage

c) Kinetic Energy Storage

Energy Storage

D. Forms of Energy Storage

2. Electro-Magnetic Storage

a) Electric Fields

b) Magnetic Fields

Energy Storage

D. Forms of Energy Storage

2. Electro-Magnetic Storage

c) Electro-Magnetic Radiation

Energy Storage

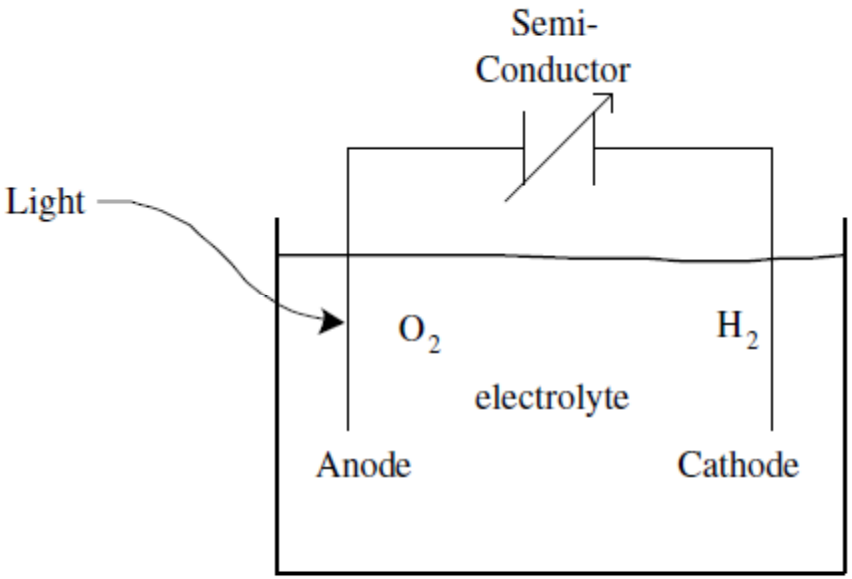
D. Forms of Energy Storage

   3. Chemical Storage

Energy Storage

D. Forms of Energy Storage

3. Chemical Storage



Energy Storage

D. Forms of Energy Storage

4. Electro-Chemical Storage

a) Battery

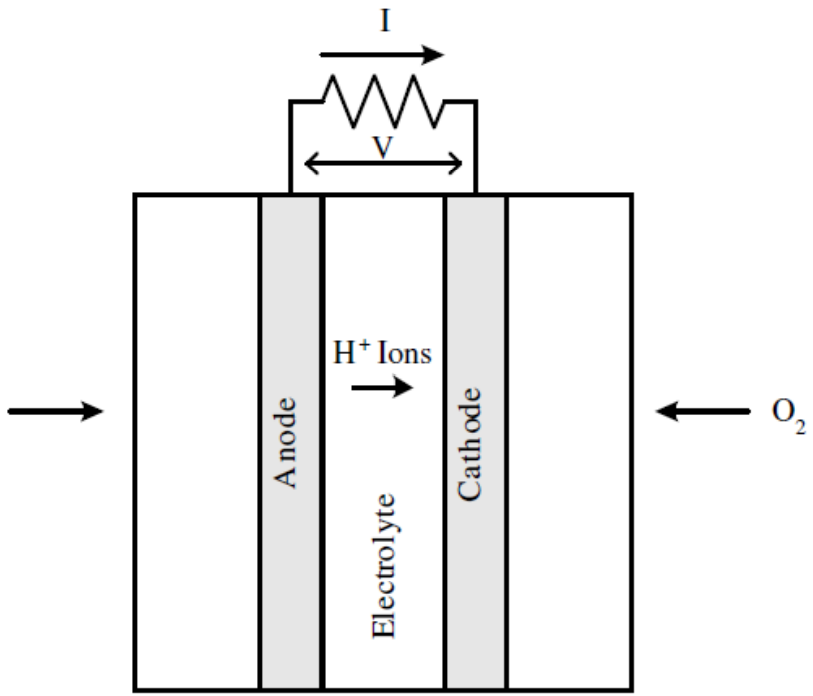
$$\mathrm{Pb} + 2\ \mathrm{H_2SO_4} + \mathrm{PbO_2} \underbrace{\rightarrow}_{\text{discharging}} \mathrm{PbSO_4} + 2\ \mathrm{H_2O} + \mathrm{PbSO_4}$$

Energy Storage

D. Forms of Energy Storage

4. Electro-Chemical Storage

b) Fuel Cell



Energy Storage

D. Forms of Energy Storage

   5. Heat Storage