Charge
Charge
Charge

- Trickle Current Charge (Overnight Charge)
- Constant Current Charge
- Constant-Current Constant-Voltage Charge
- Multi-Segment Current Charge
- Variable Current Charge
- Fuzzy Controlled Charger
- Grey-Predicted battery charger
- Phase-Locked Battery Charger
- Resistance-Compensated PLL-Based Battery Charger
- Frequency-varied Battery Pulse Charger
- Duty-Varied Battery Pulse Charger
- PLL Battery Pulse Charger
- Reflex with the Energy Recovery Function
Constant-Current and Constant-Voltage Charge
Constant-Current and Constant-Voltage Charge

- **Advantages**
  - Really reduce charge time at constant current charge state
  - Really avoid overcharge at constant voltage
  - Safe & fast

- **Imperfections**
  - 100% full charged is difficult to be obtained in short/middle time
Multi-Segment Current Charge

Advantages
- Really reduce charge time
- Fast

Imperfections
- Complex
- How to determine suitable charge currents for different SOCs
Multi-Segment Current Charge
Variable Current Charge

- Advantages
  - Really reduce charge time
  - fast

- Imperfections
  - Complex
  - How to determine suitable charge currents for different SOCs
Grey-Predicted battery charger

\[ I_c(t) = f(v_o(t), v_o(t+T)) \]

\[ v_o(t+T) \]

\[ v_o(t-3T) \]

\[ v_o(t-2T) \]

\[ v_o(t-T) \]

\[ v_o(t) \]

Demultiplexer

GM(1,1) Model
Look Up Table
(EPROM)

\[ \mu \text{ EM78447B} \]

Timer

DAC
(DAC0800)

Variable Current Generator

Controllable Current Source

\[ T \]

DAC
(ADC0804)

Battery

\[ v_o(t) \]

\[ I_c(t) \]
PLL-based Battery Charger

\[ X_i \xrightarrow{\text{Phase/Frequency Comparator}} X_e \xrightarrow{\text{LPF}} V_P \xrightarrow{\text{VCO}} X_o \]
PLL-based Battery Charger

Diagram showing the components of a PLL-based battery charger:
- Phase Comparator
- Current Pump
- Lithium-ion Battery
- Difference Amplifier
- Low Pass Filter
- VCO

Input: $f_i$
Output: $f_o$
Phase Comparator: $P_e$
Current Pump: $I_c$
Lithium-ion Battery
Difference Amplifier
VCO: $V_o$
**Phase Locked**: Yes

**Float Charge**

**Phase Tracking State**

**Frequency-Tracking State**

**Variable Current Charge Process**

**Bulk Current Charge Process**

**Frequency-Locked**

**Phase-Locked State**

**Phase Locked**: No
PLL-based Battery Charger

Input Frequency
Comparator IN

P/F
Comparator

Comparator OUT

Current Pump

10V

Li-ion Battery

VCO OUT

VCO

Current Pump

Difference Amplifier

V_o

V_h

V_o

V_h
PLL-based Battery Charger

![Graph 1](image1.png)

- Voltage (V) vs. Time (min)
- Voltage rises sharply in the initial 50 minutes, then stabilizes.

![Graph 2](image2.png)

- Current (A) vs. Time (min)
- Current decreases gradually over time, approaching a steady state.

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PLL-based Battery Charger
Resistance-Compensated PLL-Based Battery Charger

- A Li-ion Battery Pack System includes
  1. Li-ion Cell(s)
  2. Thermistor
  3. Charge-Protection Circuits (PCB, FET, Fuse, …)
  4. Optional Capacity Monitor
Resistance-Compensated PLL-Based Battery Charger
Resistance-Compensated PLL-Based Battery Charger
Resistance-Compensated PLL-Based Battery Charger
Resistance-Compensated PLL-Based Battery Charger

- The charging times for the proposed RC-PLBC and the typical PLBC are 123 and 150 min, respectively.

- The charging speed of the proposed RC-PLBC has been improved by 18% comparing with that of the typical PLBC.

- The Li-ion cell voltage $V_{bo}$ of the proposed RC-PLBC is always less than 8.4V until battery is fully charged.

- There is some extra voltage in the charging path of the Li-ion battery pack, and in reality the Li-ion cell is not overcharged in the proposed RC-PLBC.
Pulse Charge
Pulse Charge
Pulse Charge

- Advantages
  - Electrochemical characteristics are considered
  - Really reduce charge time

- Imperfections
  - Complex
  - What is the optimal pulse width for Charging
Frequency-Varied Battery Pulse Charge System

\[ Z_c \]

\[ L_c \quad C_{cl} \quad R_{cl} \quad Z_{cw} \quad R_0 \]

\[ C_{cl} \quad R_{al} \quad Z_{sw} \quad L_a \]

\[ Z_{battery} \quad + \quad ideal \]

\[ battery \quad - \]
Frequency-Varied Battery Pulse Charge System
Frequency-Varied Battery Pulse Charge System
Frequency-Varied Battery Pulse Charge System

![Graph showing voltage over time for different charge systems](image)
Duty-Varied Battery Pulse Charge System

[Diagram of battery charge system with labels: $R_0$, $R_{ct}$, $C_d$, $L_d$, $Z_d$, $Z_w$, and ideal battery.]
Duty-Varied Battery Pulse Charge System

\[ \eta = \frac{i_b}{D} \]

Pulse charging factor

\[ D_s \]

charge voltage

[Diagram showing pulse charging system with time intervals labeled as \( T_F \), \( T_S \), and \( T_C \)]
Duty-Varied Battery Pulse Charge System

```
HT46R24

A/D converter (HT46R24)

A/D converter (HT46R24)

Controller (HT46R24)

V_{cc} R_s \quad \tilde{v}_b

\text{Voltage Regulator (LM317)}

\tilde{i}_b

\text{Li-ion Battery}

\text{OPA (LM324)}

\text{ACS}

\text{OPA (LM324)}

C1384
```
Duty-Varied Battery Pulse Charge System
Duty-Varied Battery Pulse Charge System

\[ \eta = \frac{i_b}{D} \]
Duty-Varied Battery Pulse Charge System

\[ \text{Duty} \textunderscore \text{Varied Battery Pulse Charge System} \]
Duty-Varied Battery Pulse Charge System

<table>
<thead>
<tr>
<th>Charge Strategy</th>
<th>Input Charge Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVVPCS</td>
<td>590 mAh</td>
</tr>
<tr>
<td>DFVPCS with D=50%</td>
<td>599 mAh</td>
</tr>
<tr>
<td>CC-CV</td>
<td>611 mAh</td>
</tr>
</tbody>
</table>
PLL Pulse Charger

PFC

Charge Pump

UP ON

UP & DN Off

DN On

$P_{i}$

$P_{o}$

$P_{o'}$

$P_{i'}$

$I_{cp}$

$I_{p}$

$V_{o}$

VCO

LPF
PLL Pulse Charger

(a) $P_i$

(b) $P_o$

(c) $I_c$ + $I_{cp}$

(d) $I_c$ - $I_{cp}$

$T_{on}$ $T_{off}$
PLL Pulse Charger

PFC

Charge Pump

VCO

Li-ion Battery

V

CA

VA

LPF

P_i

P_o

UP

DN

P_{up}

P_{dn}

P_{up}

P_{dn}

I_{cp}

I_{cp}

V_b

I_c

C_r

V_o
PLL Pulse Charger

Average Charging Current

$T_{on}$  $T_{off}$

Bulk Current Charging  Pulsed Current Charging  Pulsed Float Charging

$I_c$
PLL Pulse Charger

![Voltage vs. Time Graph](image)

- **$P_i$**
- **$P_{o,1min}$**
- **$I_{c,1min}$**
- **$P_{o,20min}$**
- **$I_{c,20min}$**
- **$P_{o,30min}$**
- **$I_{c,30min}$**
- **$P_{o,40min}$**
- **$I_{c,40min}$**
- **$P_{o,60min}$**
- **$I_{c,60min}$**
- **$P_{o,100min}$**
- **$I_{c,100min}$**
- **$P_{o,150min}$**
- **$I_{c,150min}$**
- **$P_{o,200min}$**
- **$I_{c,200min}$**
- **$P_{o,210min}$**
- **$I_{c,210min}$**

![Current vs. Time Graph](image)

- **Ch1 Freq 29.99HZ**
- **Ch2 Freq 21.64HZ**
- **Ch2 Freq 29.74HZ**
- **Ch2 Freq 29.99HZ**
- **Ch2 Freq 29.99HZ**
- **Ch2 Freq 29.99HZ**
- **Ch2 Freq 29.99HZ**
- **Ch2 Freq 29.99HZ**
- **Ch2 Freq 29.99HZ**

- **Po,1min**
- **Po,60min**
- **Po,100min**
- **Po,150min**
- **Po,200min**
- **Po,210min**

- **Ic,1min**
- **Ic,20min**
- **Ic,30min**
- **Ic,40min**
- **Ic,50min**
- **Ic,60min**
- **Ic,100min**
- **Ic,150min**
- **Ic,200min**
- **Ic,210min**
## PLL Pulse Charger

<table>
<thead>
<tr>
<th></th>
<th>CPBC</th>
<th>PLBC</th>
</tr>
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<tbody>
<tr>
<td></td>
<td><strong>Pulsed</strong> current charging</td>
<td><strong>Pulsed</strong> float charging</td>
</tr>
<tr>
<td>Frequency-tracking state</td>
<td>Bulk current charging</td>
<td>Bulk current charging</td>
</tr>
<tr>
<td>Phase-tracking state</td>
<td></td>
<td>Variable current charging</td>
</tr>
<tr>
<td>Phase-locked state</td>
<td><strong>Pulsed</strong> float charging</td>
<td>Float charging</td>
</tr>
<tr>
<td>Charging capacity</td>
<td>678mAh</td>
<td>644mAh</td>
</tr>
<tr>
<td>Discharging capacity (Available capacity)</td>
<td>645mAh</td>
<td>603mAh</td>
</tr>
<tr>
<td>Charging efficiency</td>
<td>95.1%</td>
<td>93.6%</td>
</tr>
</tbody>
</table>
Pulse Charge with a Discharge Period (Reflex)
Pulse Charge with a Discharge Period (Reflex)

- Advantages
  - Electrochemical characteristics are considered
  - Ion diffuse and distribute more evenly
  - Really reduce charge time
  - Increase life cycle

- Imperfections
  - Complex
  - What is the optimal pulse width for Charging
  - What is the optimal discharge pulse width
Pulse Charge with a Discharge Period (Reflex)

Lead-Acid Battery, CC, Positive pole

Reflex, Positive pole
Pulse Charge with a Discharge Period (Reflex)

CC, negative pole

Reflex, negative pole
Reflex with Energy Recovery
Reflex with Energy Recovery
Reflex with Energy Recovery
Reflex with Energy Recovery
Reflex with Energy Recovery
Reflex with Energy Recovery

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of PPP</td>
<td>0.4s</td>
</tr>
<tr>
<td>Time of NPP</td>
<td>0.02s</td>
</tr>
<tr>
<td>Time of RP</td>
<td>0.06s</td>
</tr>
<tr>
<td>Maximum $I_{pp}^*$</td>
<td>25A</td>
</tr>
<tr>
<td>Maximum $I_{np}^*$</td>
<td>-20A</td>
</tr>
</tbody>
</table>
Reflex with Energy Recovery

![Graphs showing current and temperature over time with proposed RBC and typical BC comparisons.]

**Current (A) vs. Time (hour)**
- Proposed RBC
- Typical BC

**Temperature (°C) vs. Time (hour)**
- Proposed RBC
- Typical BC

- 7.3°C
- 6.9°C
Reflex with Energy Recovery

![Graph showing the relationship between time in hours and capacity in AH for Proposed RBC and Typical BC. The graph indicates that the Proposed RBC reaches 50.9 AH capacity by 3 hours, while the Typical BC reaches 45.8 AH capacity by 3 hours.](image)
Reflex with Energy Recovery

- The proposed Reflex charging technique can improve

  the charging efficiency about 10%,

  the charging speed about 8.8%, and

  the thermal deterioration effect about 5.5%.
About 1.0 AH energy is recovered by the energy recovery function.