Evaluation of Integrated Electric Plants for Great Lakes Self-Unloaders

PI: David J. Singer, Assistant Professor, Naval Architecture and Marine Engineering, University of Michigan

Co-PI: Michael G. Parsons, Arthur F. Thurnau Professor Emeritus, Naval Architecture and Marine Engineering University of Michigan

Undergraduate student: Sam Denomy, Port Huron, MI
Outline

• Definitions/Motivation
• Project goals
• Recent cargo vessel IEP example
• Study prototypes selected
• Fuel usage study
• Issues still to address
Integrated Electric Plants (IEP)

Integrated Electric Plants

Central station electric plants serving all needs including electric propulsion motors

Cruise ships, naval vessels, offshore supply vessels, ice breakers, etc.

Currently (1970-2010):

Great Lakes self-unloaders use geared diesel mechanical propulsion and small separate electrical plants for auxiliary loads – with some limited exceptions
Designer’s Comments

“electric drive should be considered for any application where the ship spends much of its time at loitering speeds, when high ship (service) power requirements exist, or where special mission power requirements dictate its use”

“all modern electric drive installations are of the integrated type with the same generators used to provide both propulsion and ship service power”

(George Stewart, ASNE/SNAME Electric Ship Design Symposium 2009).
“Experience has shown that it is not only the owner to be convinced but also and in many cases especially the yard. Having little or no experience in electric propulsion plants yards tend to consider it as a risk and overestimate all additional items and under estimate or do not consider at all the benefits and opportunities.”

Shipbuilding benefits include:
- short and straight routing of piping and cables
- possibility of extensive prefabrication and modular construction
- shortest possible installation period

“A savings of at least 50% in machinery and piping installation hours can be achieved.”

(Kanerva and Nurmi 1998)
Great Lakes Self-Unloading Bulk Carriers
almost a perfect case for IEP application

• modest power requirement due to their low speed
• varying speed profile due to the short distances and many restricted waterways, locks, and connecting channels of the Great Lakes system.

“A typical Great Lakes self-unloading bulk carrier spends about 1/3 of its operating time at reduced power and in port.” (Joe Fischer and Ed Shearer 2004).

• thruster, self-unloading and ballasting loads that are relative large fractions of the propulsion power required.
Project Recommendation from Industry

Received by GLMRI from the Great Lakes shipping industry:

“Look into developing an electric drive that would take into account the electrical use during all of our modes of operation while considering benefits such as:

- constant engine RPM
- generator loading
- maintenance and manning.”
Project goals

• Investigate the feasibility and potential benefits of using Integrated Electric Plants in future Great Lakes self-unloaders

• Considering
  arrangements
  effects on cargo capacity at constant draft
  fuel usage and environmental emissions over all operating modes
  manning
  overall ship life-cycle economics
Recent Cargo Vessel IEP Example

TOTE Orca Class RO-RO Vessels

from Maritech supported study of 17 alternatives

final design used four large and two small generators
Advantages and Disadvantages of IEP

Advantages

- reduced number of prime movers (diesels) possible
- engines can be run closer to sweet spot in all modes
- more flexible arrangements
- can eliminate gearing
- can eliminate need for CRP propeller
- reduced maintenance
- fuel use can be less
- emissions can be less

Disadvantages

- may require more volume
- greater weight – problematic on weight-limited bulk carriers
- about 7% loss in transmission efficiency (diesel to propeller)
- greater capital cost
Comparison of Prime Mover Brake Power

Prime mover brake power $P_B = P_E/(\eta_H \eta_R \eta_o \eta_T \eta_S \eta_B)$

Geared diesel drive with Controllable Reversible Propeller (CRP)
  with $\eta_T = \eta_g = 0.97$ and $\eta_o = 0.65$ (approx.)

AC/AC electric drive with Fixed Pitch Propeller (FPP)
  With $\eta_T = \eta_{gen} \eta_{sw} \eta_{tr} \eta_{fc} \eta_{m}$
  $= 0.96 \times 1.00 \times 0.99 \times 0.98 \times 0.96 = 0.894$
  and $\eta_o = 0.66$ (approx.,+1.5% better)

Net effect $= 0.97 \times 0.65/(0.96 \times 1.00 \times 0.99 \times 0.98 \times 0.96 \times 0.66) = 1.068$
Diesel Generator Specific Fuel Rate – Constant RPM

want all loaded diesels in the 80-100% load range
# Principal Characteristics of Study Prototypes

<table>
<thead>
<tr>
<th></th>
<th>1000 ft (Poe-max) Self-Unloader</th>
<th>730 ft (MacArthur-max) Self-Unloader</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LOA</strong></td>
<td>1000 ft</td>
<td>730 ft</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>105 ft</td>
<td>78 ft</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>56 ft</td>
<td>45 ft</td>
</tr>
<tr>
<td><strong>Design T</strong></td>
<td>27.5 ft</td>
<td>27.5 ft</td>
</tr>
<tr>
<td><strong>Service speed</strong></td>
<td>14.0 kts</td>
<td>14.0 kts</td>
</tr>
<tr>
<td><strong>Capacity</strong></td>
<td>80,900 gross tons</td>
<td>37,300 gross tons</td>
</tr>
<tr>
<td><strong>Current propulsion power</strong></td>
<td>14,000 hp = 10,440 kW</td>
<td>7,000 hp = 5,220 kW</td>
</tr>
<tr>
<td><strong>Number shafts</strong></td>
<td>twin screw</td>
<td>single screw</td>
</tr>
<tr>
<td><strong>Propellers</strong></td>
<td>17.5 ft. dia., 120 rpm FPP</td>
<td>17.5 ft dia., 120 rpm FPP</td>
</tr>
<tr>
<td><strong>Bow thruster</strong></td>
<td>1200 kW</td>
<td>800 kW</td>
</tr>
<tr>
<td><strong>Stern thruster</strong></td>
<td>1200 kW</td>
<td>800 kW</td>
</tr>
<tr>
<td><strong>Hold-loop belt drive</strong></td>
<td>2 @ 750 kW = 1500 kW</td>
<td>conveyor system total</td>
</tr>
<tr>
<td><strong>Boom belt drive</strong></td>
<td>2 @ 430 kW = 860 kW</td>
<td>1300 kW</td>
</tr>
<tr>
<td><strong>Ballast pumps</strong></td>
<td>4 @ 120 kW = 480kW</td>
<td>2 @ 120 kW = 240 kW</td>
</tr>
<tr>
<td><strong>Ship service power</strong></td>
<td>466.6 kW, max. during docking</td>
<td>510 kW, max. during docking</td>
</tr>
<tr>
<td><strong>Design prototype</strong></td>
<td>MV Walter J. McCarthy</td>
<td>MV American Mariner</td>
</tr>
</tbody>
</table>
## Operating Profile – Duluth, MN to Gary, IN

<table>
<thead>
<tr>
<th>mode of operation</th>
<th>percent propulsion power</th>
<th>auxiliaries in use</th>
<th>hours per round trip</th>
<th>percent round trip time</th>
</tr>
</thead>
<tbody>
<tr>
<td>loading</td>
<td>0.0%</td>
<td>ship service, ballast pumps</td>
<td>6.0</td>
<td>4.4%</td>
</tr>
<tr>
<td>maneuvering</td>
<td>30.0%</td>
<td>ship service</td>
<td>6.0</td>
<td>4.4%</td>
</tr>
<tr>
<td>reduced speed</td>
<td>50.0%</td>
<td>ship service</td>
<td>8.0</td>
<td>5.9%</td>
</tr>
<tr>
<td>open lake</td>
<td>85.0%</td>
<td>ship service</td>
<td>103.0</td>
<td>76.3%</td>
</tr>
<tr>
<td>locking/docking</td>
<td>10.0%</td>
<td>ship service, thrusters</td>
<td>2.0</td>
<td>1.5%</td>
</tr>
<tr>
<td>unloading</td>
<td>0.0%</td>
<td>ship service, ballast pumps, conveyors,</td>
<td>10.0</td>
<td>7.4%</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td></td>
<td></td>
<td><strong>135.0</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>
1000’ IEP Self-Unloader (all EPA Tier II)

• New M/V Walter J. McCarthy, Jr.
  diesel mechanical CRP drive
  4 x EMD 16-710G7C-T2 2629 kW engines, generators on 2
  2 x Cat 600 kWe generators

• IEP Design using Caterpillar Generators
  4 x Cat C280-8 2420 kWe generators
  2 x Cat 3508B 910 kWe generators

• IEP Design using Wärtsilä Generators
  4 x Wärtsilä 9L26 2810 kWe
  1 x Wärtsilä 6L20DF 1014 kWe
Summary of 1000’er Results

\[
\text{fuel/voyage} = \sum_{\text{modes}} \sum_{\text{generators operating}} (\text{gm/kWh})(\text{kW/mode})(\text{h/voyage})
\]

<table>
<thead>
<tr>
<th>design</th>
<th>effective t/h</th>
<th>fuel $/voyage</th>
<th>savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Walter J. McCarthy, Jr.</td>
<td>1.744</td>
<td>$129,459</td>
<td>base</td>
</tr>
<tr>
<td>IEP with Caterpillar generators</td>
<td>1.620</td>
<td>$120,269</td>
<td>$9,190 (7.1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(4.1% due to sfr)</td>
</tr>
<tr>
<td>IEP with Wärtsilä Generators</td>
<td>1.536</td>
<td>$114,024</td>
<td>$15,435 (11.9%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(7.9% due to sfr)</td>
</tr>
</tbody>
</table>

based on $550/tonne fuel
730’ IEP Self-Unloader (all EPA Tier II)

- New M/V *American Mariner*
  - diesel mechanical CRP drive
  - 2 x EMD 16-710G7C-T2 2629 kW engines
  - 4 x Cat 600 kW generators

- IEP Design using Caterpillar Generators
  - 2 x Cat C280-8 2200 kW generators
  - 2 x Cat 3508B 715 kW generators

- IEP Design using Wärtsilä Generators
  - 2 x Wärtsilä 9L26 2810 kW
  - 1 x Wärtsilä 6L20DF 1014 kW
Summary of 730’er Results

\[ \text{fuel/voyage} = \sum_{\text{modes}} \sum_{\text{generators operating}} (\text{gm/kWh})(\text{kW/\text{mode}})(\text{h/voyage}) \]

<table>
<thead>
<tr>
<th>design</th>
<th>effective t/h</th>
<th>fuel $/voyage</th>
<th>savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>New American Mariner</td>
<td>0.884</td>
<td>$65,659</td>
<td>base</td>
</tr>
<tr>
<td>IEP with Caterpillar generators</td>
<td>0.841</td>
<td>$62,430</td>
<td>$3,229 (4.9%) (4.1% due to sfr)</td>
</tr>
<tr>
<td>IEP with Wärtsilä generators</td>
<td>0.798</td>
<td>$59,259</td>
<td>$6,400 (9.8%) (7.9% due to sfr)</td>
</tr>
</tbody>
</table>

Based on $550/tonne fuel
Issues Still to Address

- Emissions study following Harkins’ methodology
  
  *(Marine Technology, July, 2007)*

- Arrangements development, weight impacts

- Modular generators on main deck

- Modular generators owned by manufacturer with kWh purchased as an operating cost, including major maintenance; reduced capital cost

- LNG use, particularly after 2015

- Economics study
Special thanks to
Noel L. Bassett, Acting President
American Steamship Company, Williamsville, NY for details on the
M/V Walter J. McCarthy, Jr. and the M/V American Mariner

John F. Hatley, Americas Vice President Ship Power
Wärtsilä North America, Houston, TX

Questions?