HYBRID ELECTRIC VEHICLES:
Simulation, Design, & Implementation

Fall 2004 – IPRO 326 – Illinois Institute of Technology

AN INTRODUCTION TO IPRO 326

Presenter: **SADIA SADIQ**
[Team Leader]

The Ipro 326 TEAM

Faculty Advisor:

Dr. Ali Emadi – ECE Department, F

Team Members:

Sadia Sadiq 3rd year, ECE Chad Johnson

Ali Naqvi 4th year, ECE Mahdi Mohamma

Paul Reinhard 5th year, MMAE Jeffrey Stano

Marta Bastrzyk 3rd year, MMAE Gregory Waliczek

Thomas Hittie 3rd year, MMAE Tiana Washingto

Theresa Hudik 3rd year, MMAE

* Special thanks to IIT Ph.D. candidate Sheldon Williamson for his help with the Hybrid Bus Research and Simulations.

Objectives

- Determine optimum HF for parallel and series configurations of Hummer H2
- Determine optimum HF for parallel and series configurations of HMMWV (High-Mobility Multipurpose Wheeled Vehicle) M1097 A2
- Simulate a hybrid electric bus system scheduled to have practical implementations in India by the end of the next year, 2005

Technical Team Organization

- Technical tasks were divided as the following:

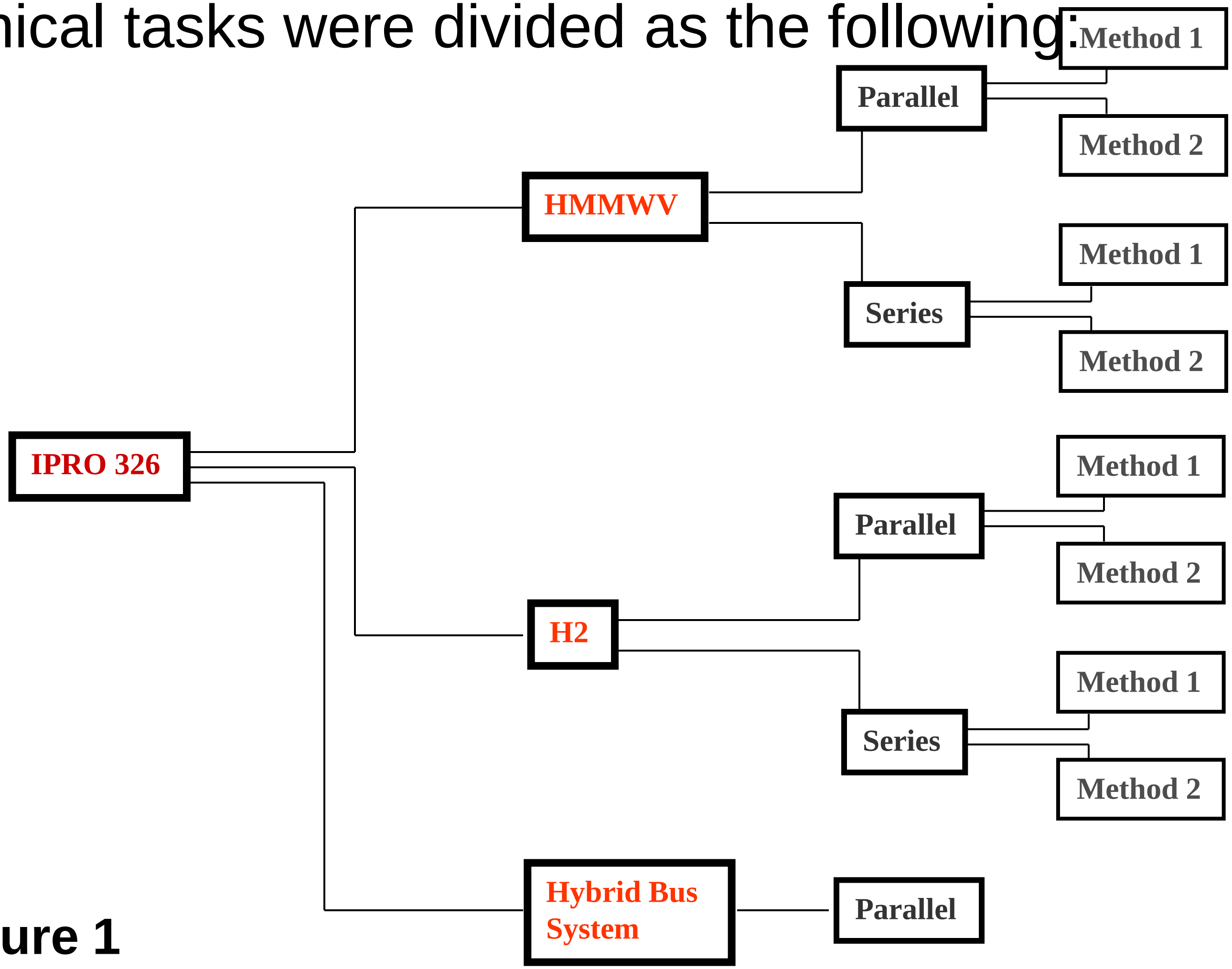


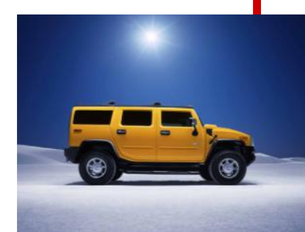
Figure 1

Presentation Outline

- An Introduction to Hybrid Electric Vehicles and Our Technical Approach

- HMMWV M1097 A2: Parallel CONFIGURATION
- HMMWV M1097 A2 : Series CONFIGURATION

- Hummer H2 : Parallel CONFIGURATION
- Hummer H2 : Series CONFIGURATION
- Hybrid Electric Bus System
- Conclusion



An Introduction To Hybrid Electric Vehicles & Our Technical Approach

Presenter: **PAUL REINHARD**
[Technical Leader]

What is a Hybrid Electric Vehicle (HEV)?

- HEVs combine the internal combustion engine (ICE) with an electric motor
- Extra batteries to handle higher electric loading
- Benefits include: higher fuel economy (MPG), extended range, more environmentally friendly
- Can be integrated into a wide range of applications: personal transportation to military applications and commercial hauling
- There are two types of HEVs: SERIES and PARALLEL

Series HEV Configuration

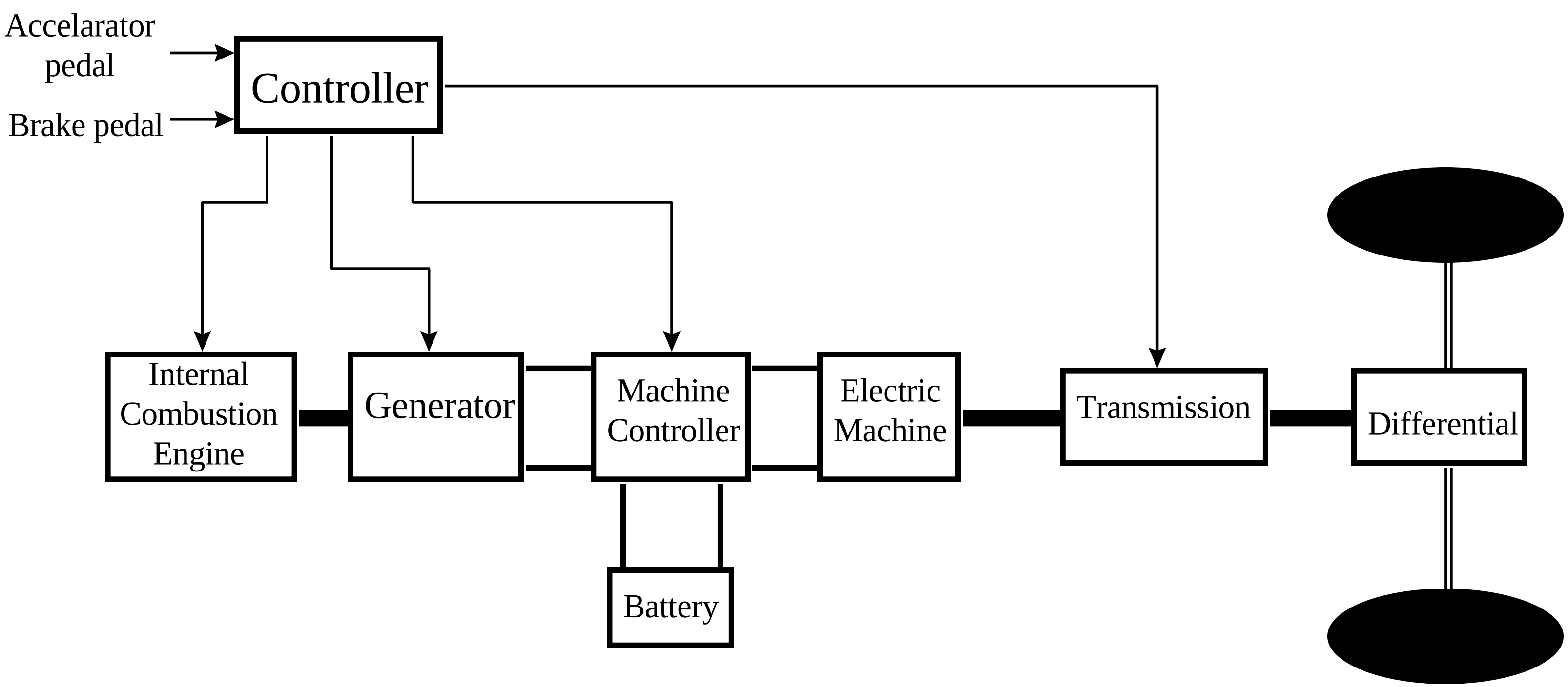


Figure 2: ICE charges the batteries or powers the electric motor which drives the transmission.

Parallel HEV Configuration

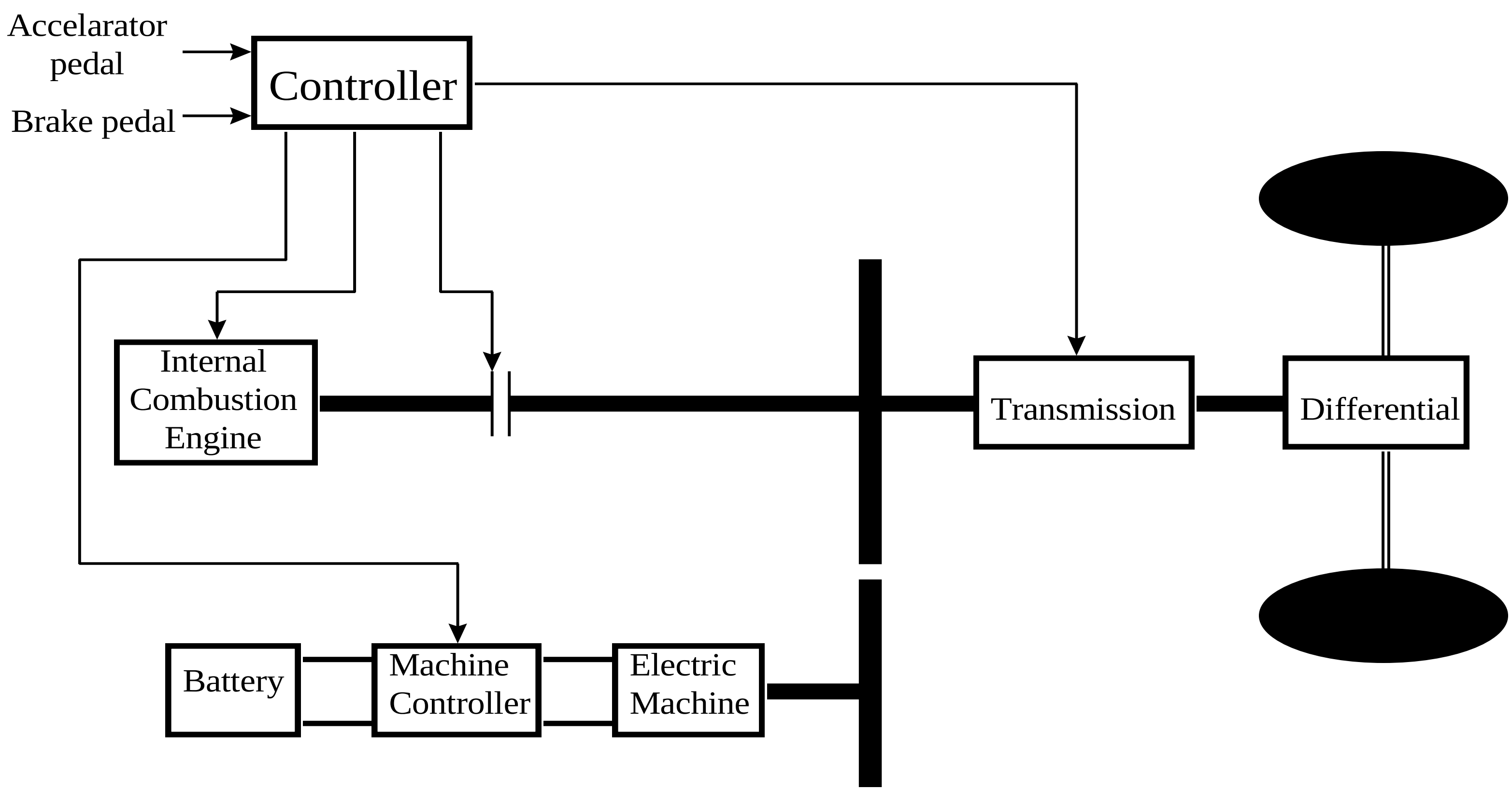


Figure 3: ICE and electric motor can both drive the transmission.

The Hybridization Factor

- Ratio of the electric motor in comparison to the total vehicle power
- Optimum hybridization factor yields highest fuel economy for the vehicle
- Two test methods used for each series and parallel configurations, for both vehicles, to determine the optimum hybridization factor:

  - Parallel Configuration
    - Method 1: total vehicle power constant
    - Method 2: internal combustion engine power constant

  - Series Configuration
    - Method 1: motor power constant
    - Method 2: internal combustion engine power constant

- All testing and simulations were done with ADVISOR (Advanced Vehicle Simulator)
  - Software used to simulate hybrid electric, conventional, electric, and fuel cell vehicles.
  - Calculates fuel economy, emissions released, acceleration times, etc. for a given drive cycle.

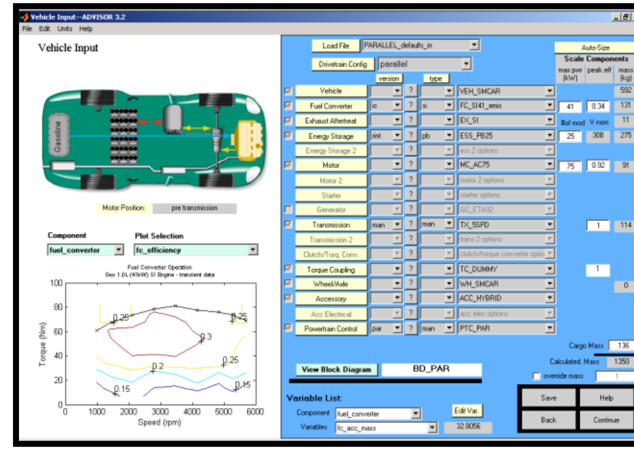


Figure 4

- Three Drive Cycles tested in this project:
  1) UDDS (Urban Dynamometer Driving Schedule) – City Drive Cycle
  2) HWFET (Highway Fuel Economy Test) – Highway Drive Cycle
  3) HL07 – “High Stress” Engineered Cycle that tests vehicles for various accelerations over a range of speeds.

The HMMWV M1097 A2

- HMMWV detailed parameters:

	HMMWV (M1097 A2)
1. Coefficient of Drag	0.5
2. Vehicle Mass	5900 lbs
3. Vehicle Frontal Area	4902 in. sq.
4. Vehicle Wheel Base	130 in.
5. Vehicle Cargo Mass (Payload)	360 lbs.
6. Fraction of vehicle weight	43.70%
front axle when standing still	
7. Height of vehicle center-of-gravity	31.8 in.
above the road	
8. Transmission Weight	GM Turbo 400 (3L80)
9. Engine Weight	756 lbs

Table 1

The HUMMER H2

- H2 detailed parameters:

	HUMMER (H2)
1. Coefficient of Drag	0.57
2. Vehicle Mass	6400 lbs
3. Vehicle Frontal Area	6094.4 in sq. (w/o mirrors)
4. Vehicle Wheel Base	122.8 in.
5. Vehicle Cargo Mass (Payload)	255 lbs.
6. Fraction of vehicle weight	46.50%
front axle when standing still	
7. Height of vehicle center-of-gravity	34.0 in.
above the road	
8. Transmission Weight	Hydromatic 4L65-E 184 lbs
9. Engine Weight	Vortec 6000 0 L V8 565 lbs

Table 2

HMMWV (High-Mobility Multipurpose Wheeled Vehicle) M1097 A2:

PARALLEL CONFIGURATION

Presenter: **Tiana Washington**
Team Members: Thomas Hittie & Theresa Hudik

Simulation Methods

1) Constant Motor Power
   - Engine power is scaled from 100% to 30%, and the motor power is scaled from 0% to 70% in increments of 5%

2) Varying Motor Power
   - Motor power is scaled from 0% to 70% in increments of 5%, and the engine power was kept constant at 100%

Note:

The hybrid vehicle runs with the least possible number of battery modules to meet the UDDS cycle.

Fuel Economy Results – METHOD 1

- **Method 1:**
  - Best MPG for the City Cycle was reached when the engine was scaled down to 50kW (50.5%) with 29 battery modules and HF = 0.50
  - Best MPG for the Highway Cycle was also reached when the engine was scaled down to 50kW (50.5%) with 29 battery modules and HF = 0.50

	UDDS	**HWY**
MPG	15.2	23.2
Improvement	43.4%	23.4%

Table 3

Fuel Economy Chart – METHOD 1

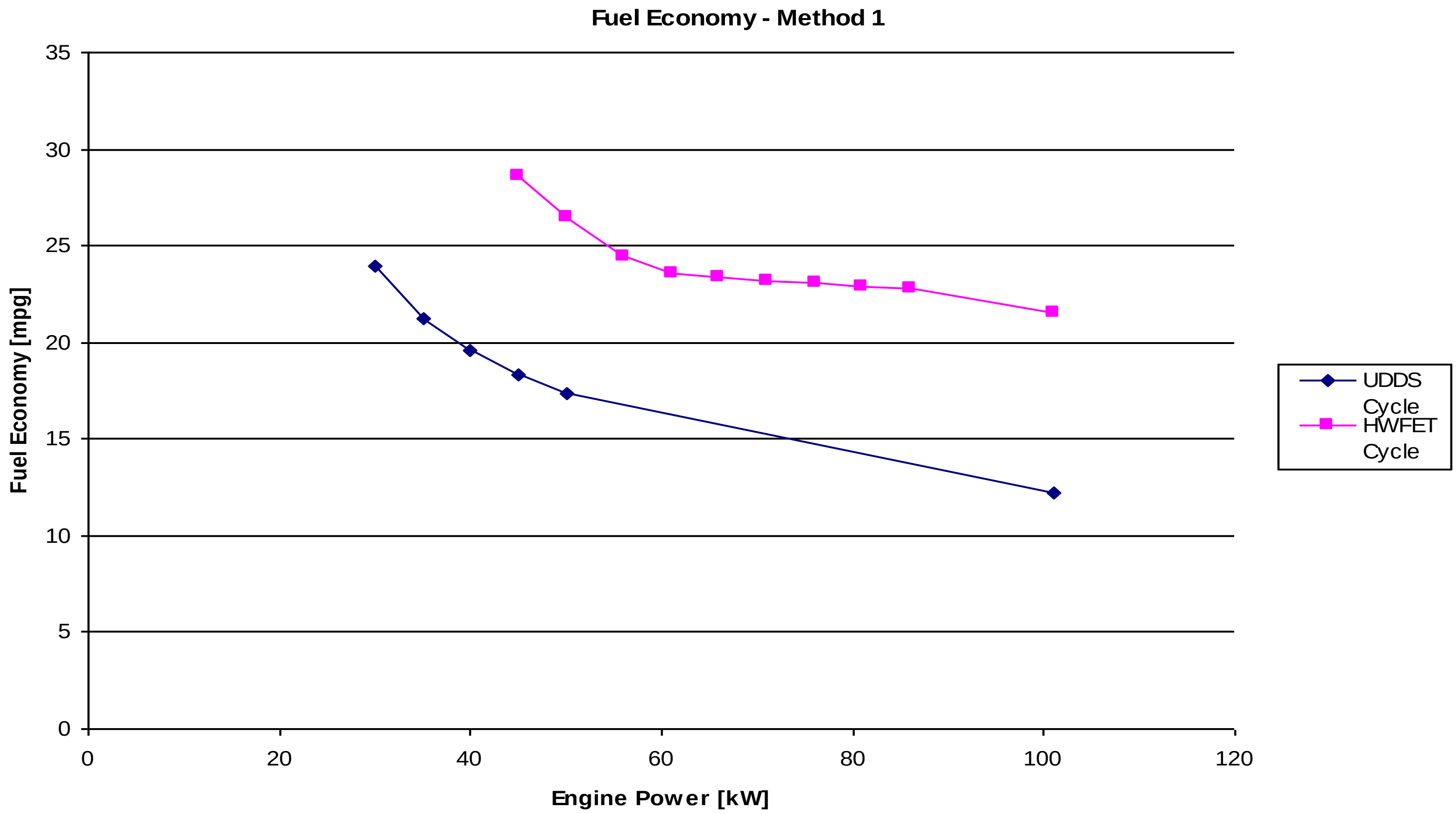


Figure 5: Variation in miles per gallon (mpg) over the range of engine power (kW)

Fuel Economy Results – METHOD 2

- **Method 2:**
  - Best MPG for the City Cycle was reached when the motor was scaled up to 40kW (40%) with 23 battery modules and HF = 0.40
  - Best MPG for the Highway Cycle was also reached when the motor was scaled up to 40kW (40%) with 23 battery modules and HF = 0.40

	UDDS	HWY
MPG	9.90	18.90
Improvement	-6.60%	0.53%

Table 4

Fuel Economy Chart – METHOD 2

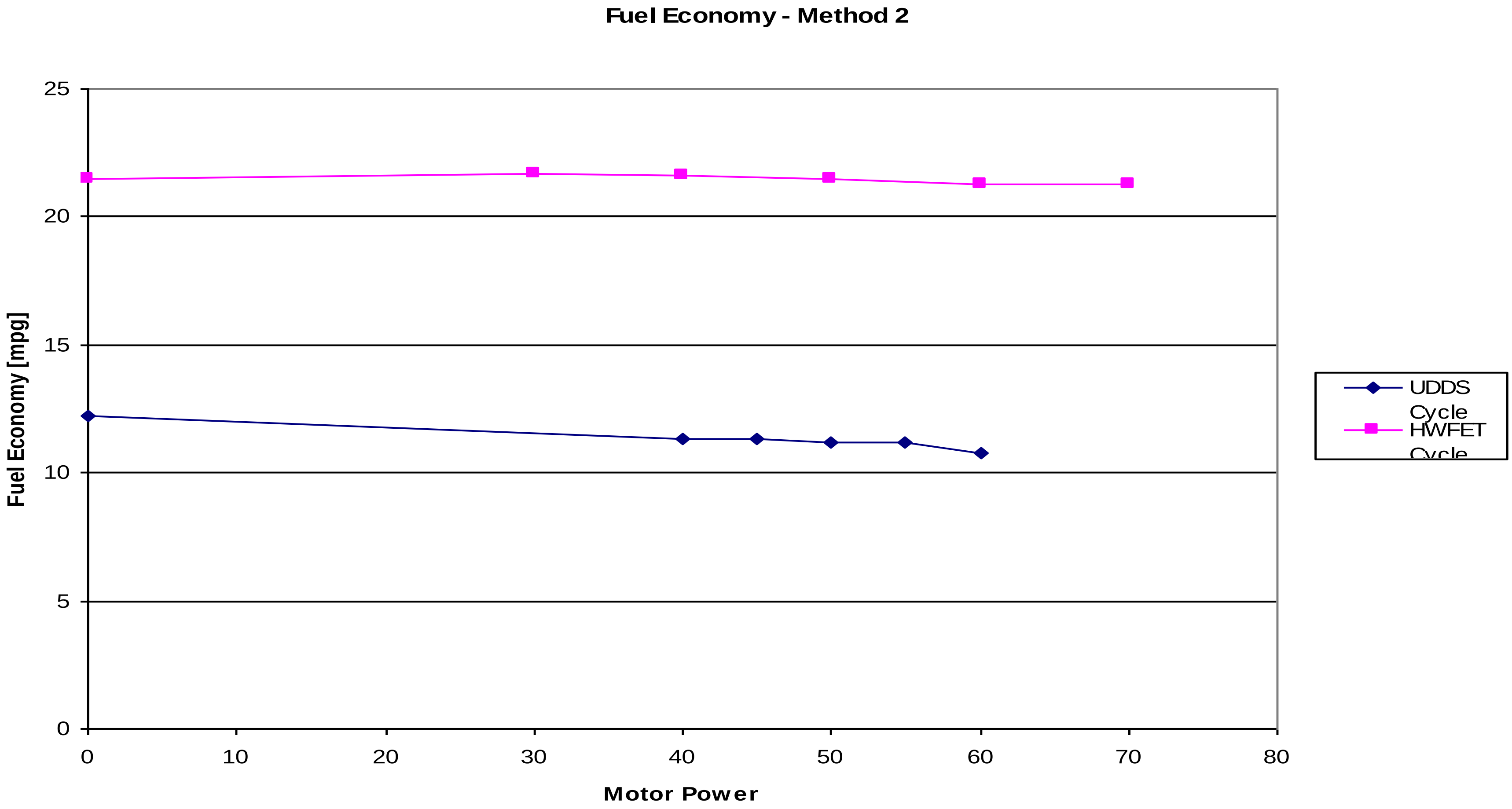


Figure 6: Variation in miles per gallon (mpg) over the range of engine p

Hybrid VS. Conventional

					Fuel Economy [mpg]	
	HF	0-60 mph	0-50 mph	Max Speed	City	Highway
Conventional	N/A	10.70s	33.4s	80.5 mph	10.6	18.8
Hybrid Method 1	0.50	9.60s	18.5s	95.6 mph	15.2	23.2
Hybrid Method 2	0.40	8.40s	17.0s	105.9 mph	9.90	18.9

Table 5

Conclusion:

- Both the performance and fuel economy of Method 1 hybridized Parallel HMMWV increased when compared with conventional values.
- However only the performance, not the fuel economy, of Method 2 hybridized Parallel HMMWV increased.

HMMWV (High-Mobility Multipurpose Wheeled Vehicle) M1097 A2:

SERIES CONFIGURATION

Presenter: **Marta Bastrzyk**
Team Members: Jeffrey Stano & Gregory Waliczek

Simulation Methods

1) Constant Motor Power
   - Engine and generator are scaled from 100% to 30% in increments of 5%
2) Varying Motor Power
   - Motor power is scaled from 60% to 140% in increments

Note:

The hybrid vehicle runs with the least possible number of battery modules to meet the UDDS cycle.

Fuel Economy Results – METHOD 1

- **Method 1:**
  - Best MPG for the City Cycle was reached when the engine and generator were scaled down to 99kW (85%) with 19 battery modules and HF = 0.15
  - Best MPG for the Highway Cycle was reached when the engine and generator were scaled down to 35kW (30%) with 25 battery modules and HF = 0.70

	UDDS	HWY
MPG	20.6	44.9
Improvement	90.7%	138%

Table 6

Fuel Economy Chart – METHOD 1

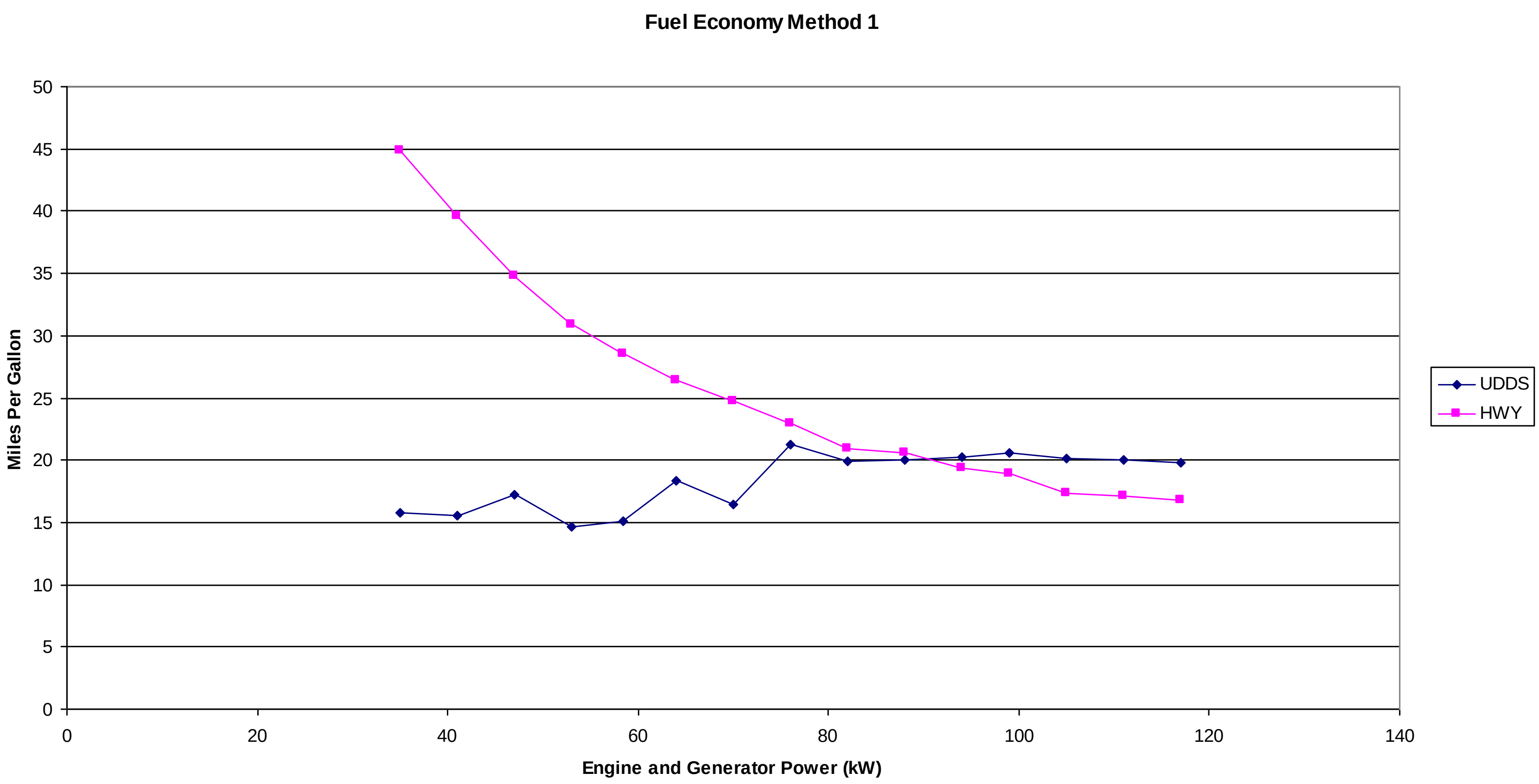


Figure 7: Variation in miles per gallons (mpg) over the range of engine p

Fuel Economy Results – METHOD 2

- **Method 2:**
  - Best MPG for the City Cycle was reached when the motor was scaled down 82kW (70%) with 19 battery modules and HF = 0.30
  - Best MPG for the Highway Cycle was reached when the motor was scaled down to 82kW (70%) with 19 battery modules and HF = 0.05

	UDDS	HWY
MPG	20.5	19.1
Improvement	89.8%	1.6%

Table **7**

Fuel Economy Chart – METHOD 2

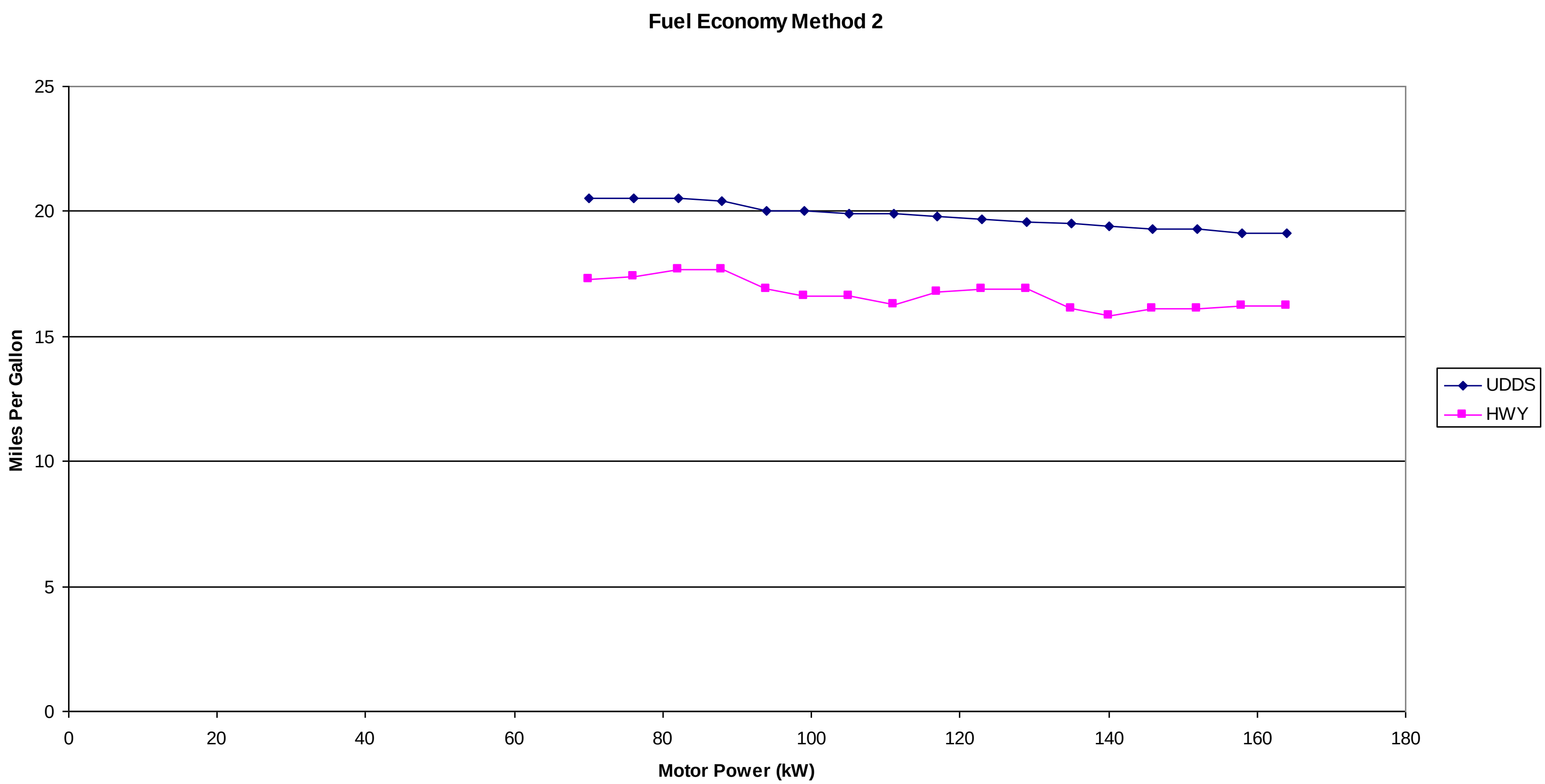


Figure 8: Variation in miles per gallon (mpg) over the range of engine po

Hybrid VS. Conventional

					Fuel Economy [mpg]	
	HF	0-60 mph	0-50 mph	Max Speed	City	Highway
Conventional	N/A	9.50s	27.8s	87.8 mph	10.8	18.8
Hybrid Method 1	0.20	6.40s	17.9s	80.6 mph	20.2	19.4
Hybrid Method 2	0.05	7.00s	18.7s	80.7 mph	19.0	20.5

Table 8

Conclusion:

Both the performance and fuel economy of the hybridized HMMWV M1097 A2 result in high increase when compared with conventional values.

<u>Hummer H2:</u>

PARALLEL CONFIGURATION

Presenter: **Thomas Hittie**
Team Members: Chad Johnson & Tiana Washington

Simulation Methods

1) Constant Total Power

- Engine was scaled from 100% to 30%, and motor was scaled from 0% to 70% in increments of 5%

2) Constant Engine Power

- Motor power was scaled from 5kW to 70kW in incremen

Note:

The hybrid vehicle runs with the least possible number of battery modules to meet the UDDS cycle.

Fuel Economy Results – METHOD 1

- **Method 1:**
  - Best MPG for the City Cycle was reached when the engine and motor were scaled down to 104kW and 156kW respectively, with 10 battery modules and HF = 0.60
  - Best MPG for the Highway Cycle was reached when the engine and motor were scaled down 169kW and 91kW respectively, with 9 battery modules and HF = 0.35

	UDDS	HWY
MPG	14.2	16.7
Improvement	47.9%	21.0%

Table 9

Fuel Economy Chart – METHOD 1

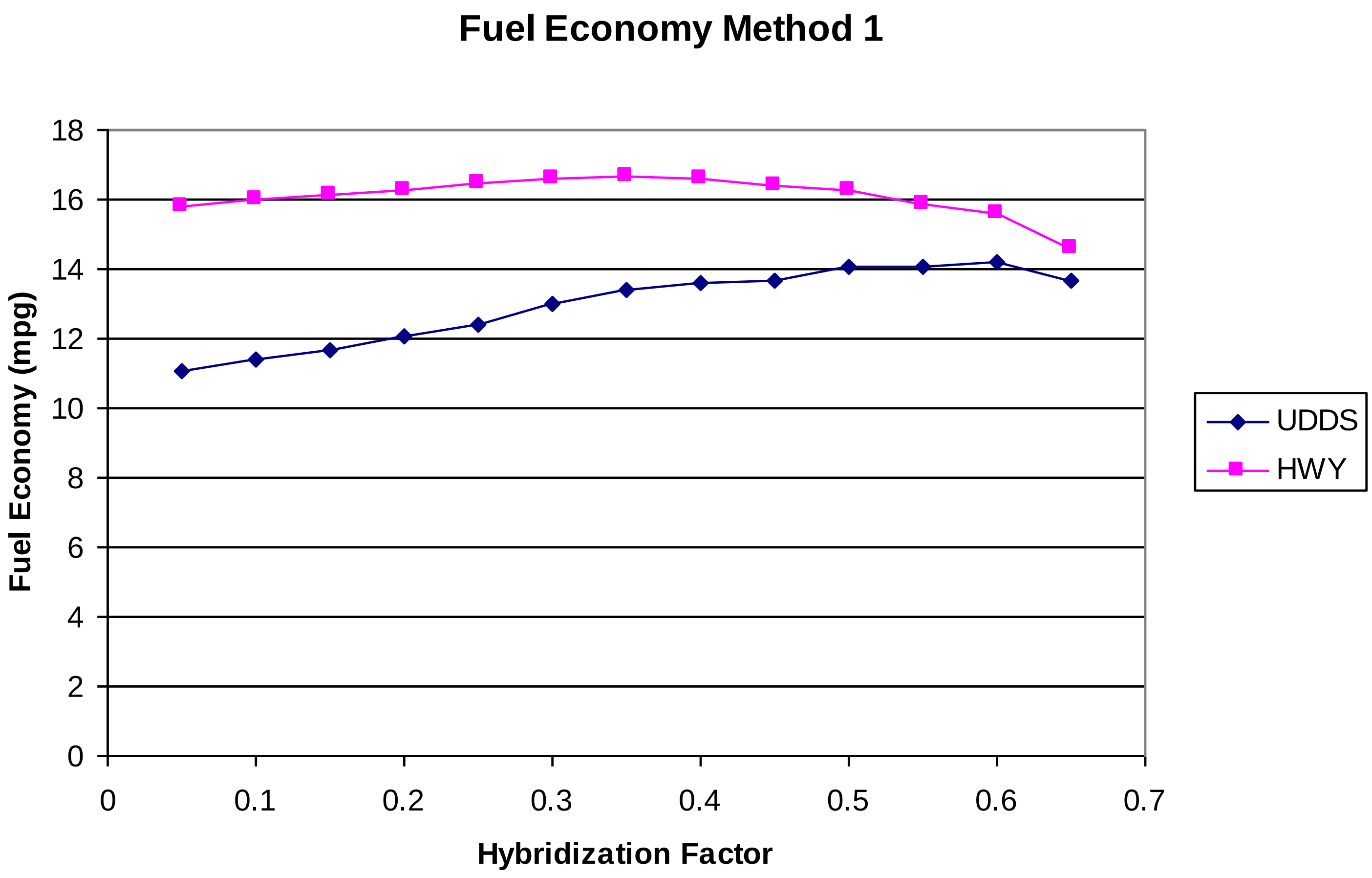


Figure 9: Variation in miles per gallon (mpg) over the range of

Fuel Economy Results – METHOD 2

- **Method 2:**
  - Best MPG for the City Cycle was reached when the motor was greater than 10kW
  - Best MPG for the Highway Cycle was reached when the motor was at 70kW with 19 battery modules and HF = 0.212

	UDDS	HWY
MPG	10.9	19.1
Improvement	13.5%	18.8%

Table 10

Fuel Economy Chart – METHOD 2

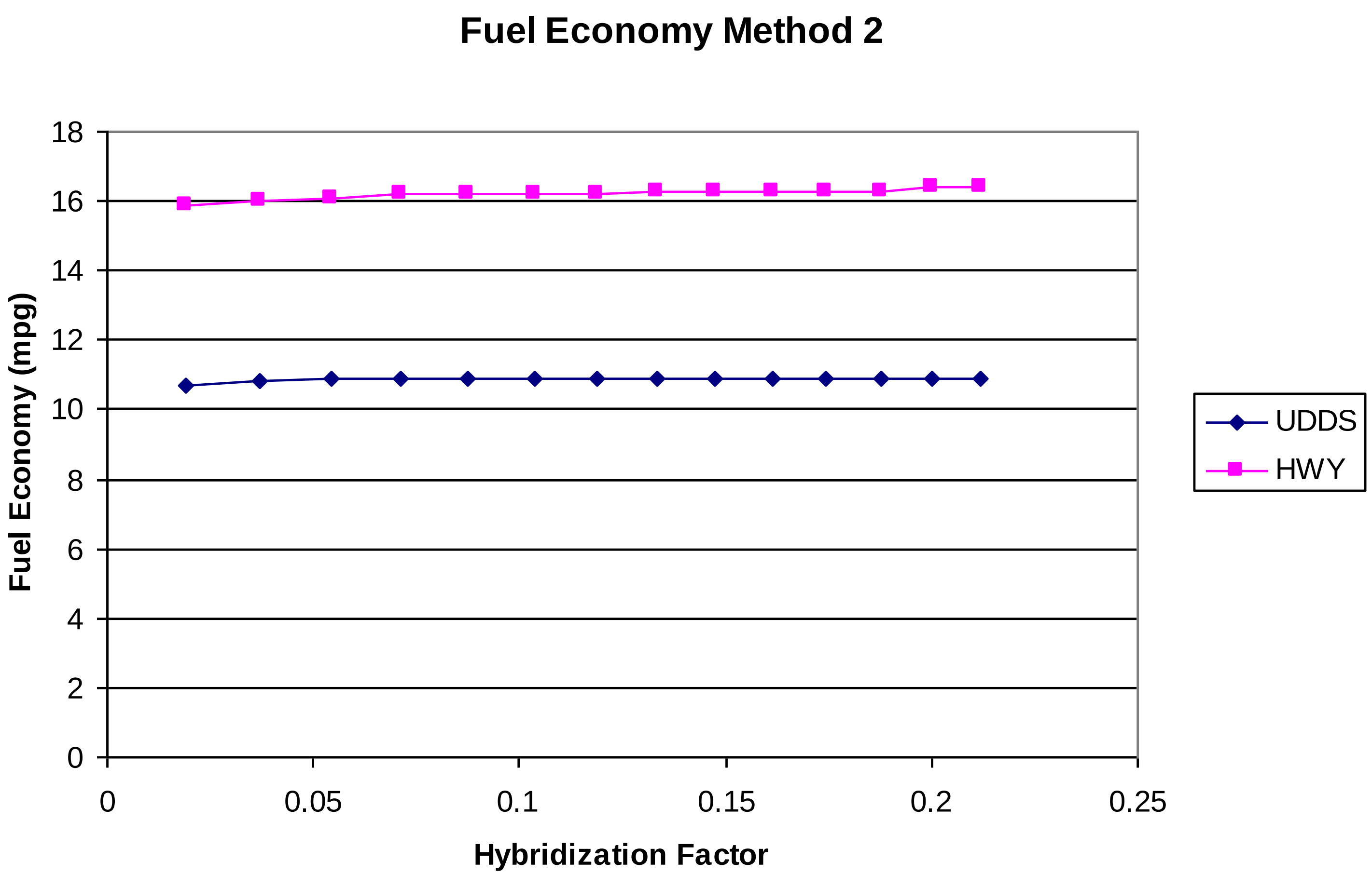


Figure 10: Variation in miles per gallon (mpg) over the range o

Hybrid VS. Conventional

	HF	0-60 mph	0-50 mph	Max Speed	Fuel Economy [mpg] City	Fuel Economy [mpg] Highway
Conventional	N/A	9.80s	17.9s	101.2 mph	9.60	13.8
Hybrid Method 1	0.05	10.3s	18.2s	101.7 mph	11.1	15.8
Hybrid Method 2	0.212	9.50s	17.5s	115.3 mph	10.9	16.4

Table 11

Conclusion:

The change in performance of the hybridized parallel HUMMER H2, except at max speed of

Method 2, is negligible, while both methods dramatically increase fuel economy.

Hummer H2:

SERIES CONFIGURATION

Presenter: **Jeffrey Stano**
Team Members: Marta Bastrzyk & Gregory Waliczek

Simulation Methods

1) Constant Motor Power
   - Engine and generator are scaled from 100% to 30% in increments of 5%
2) Varying Motor Power
   - Motor power is scaled from 60% to 140% in increments

Note:

The hybrid vehicle runs with the least possible number of battery modules to meet the UDDS cycle.

Fuel Economy Results – METHOD 1

- **Method 1:**
  - Best MPG for the City Cycle was reached when the engine and generator were scaled down to 169kW (65%) with 34 battery modules and HF = 0.35
  - Best MPG for the Highway Cycle was reached when the engine and generator were scaled down to 156kW (60%) with 36 battery modules and HF = 0.70

	UDDS	**HWY**
MPG	21.6	18.0
Improvement	118%	26%

Table 12

Fuel Economy Chart – METHOD 1

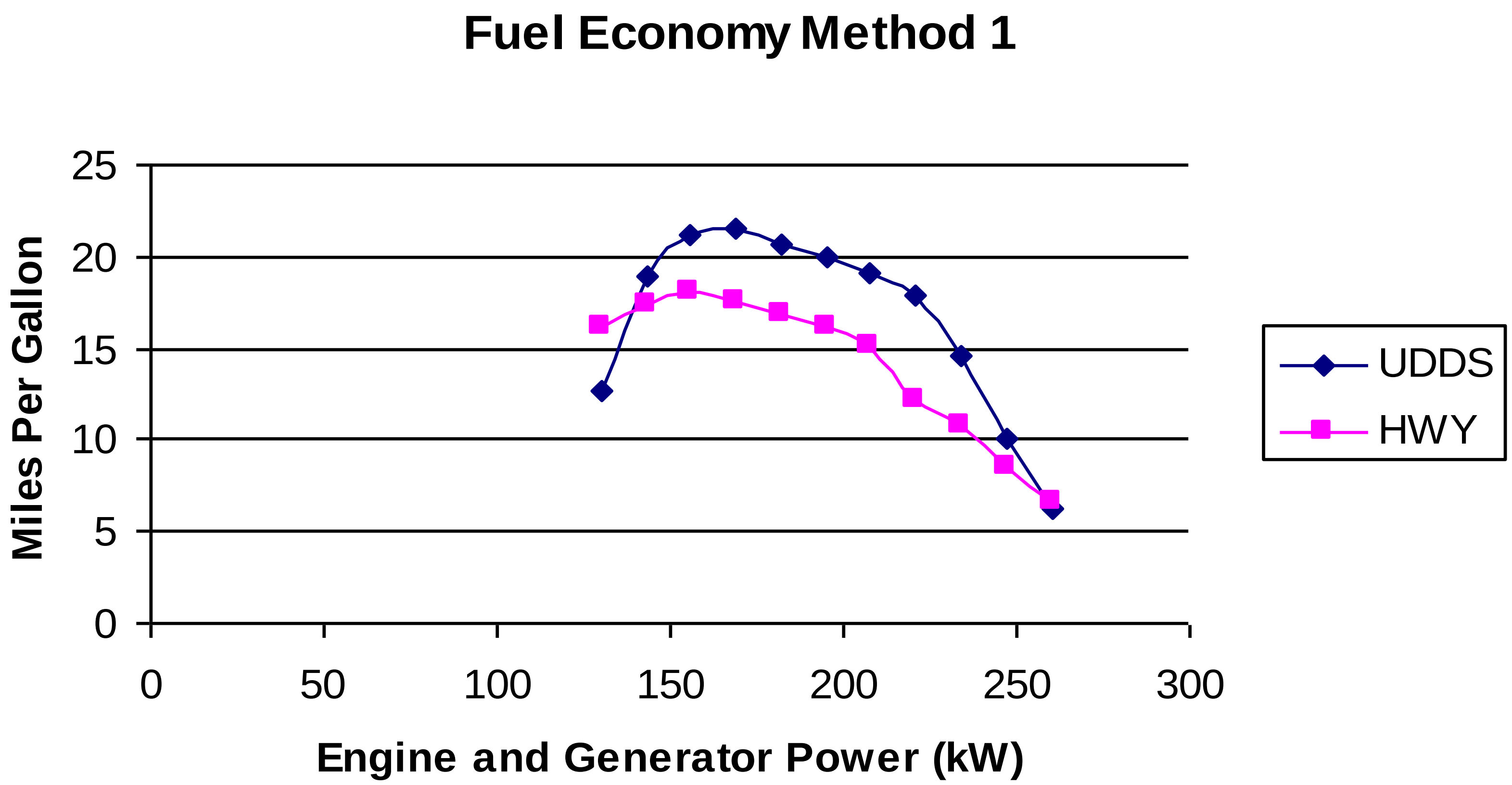


Figure 11: Variation in miles per gallon (mpg) over the range of

Fuel Economy Results – METHOD 2

- **Method 2:**
  - Best MPG for the City Cycle was reached when the motor was scaled up to 273kW (105%) with 14 battery modules and HF = 0.05
  - Best MPG for the Highway Cycle was reached when the motor was scaled down to 325kW (125%) with 15 battery modules and HF = 0.20

	UDDS	HWY
MPG	5.8	6.3
Improvement	-41%	-56%

Table 13

Fuel Economy Chart – METHOD 2

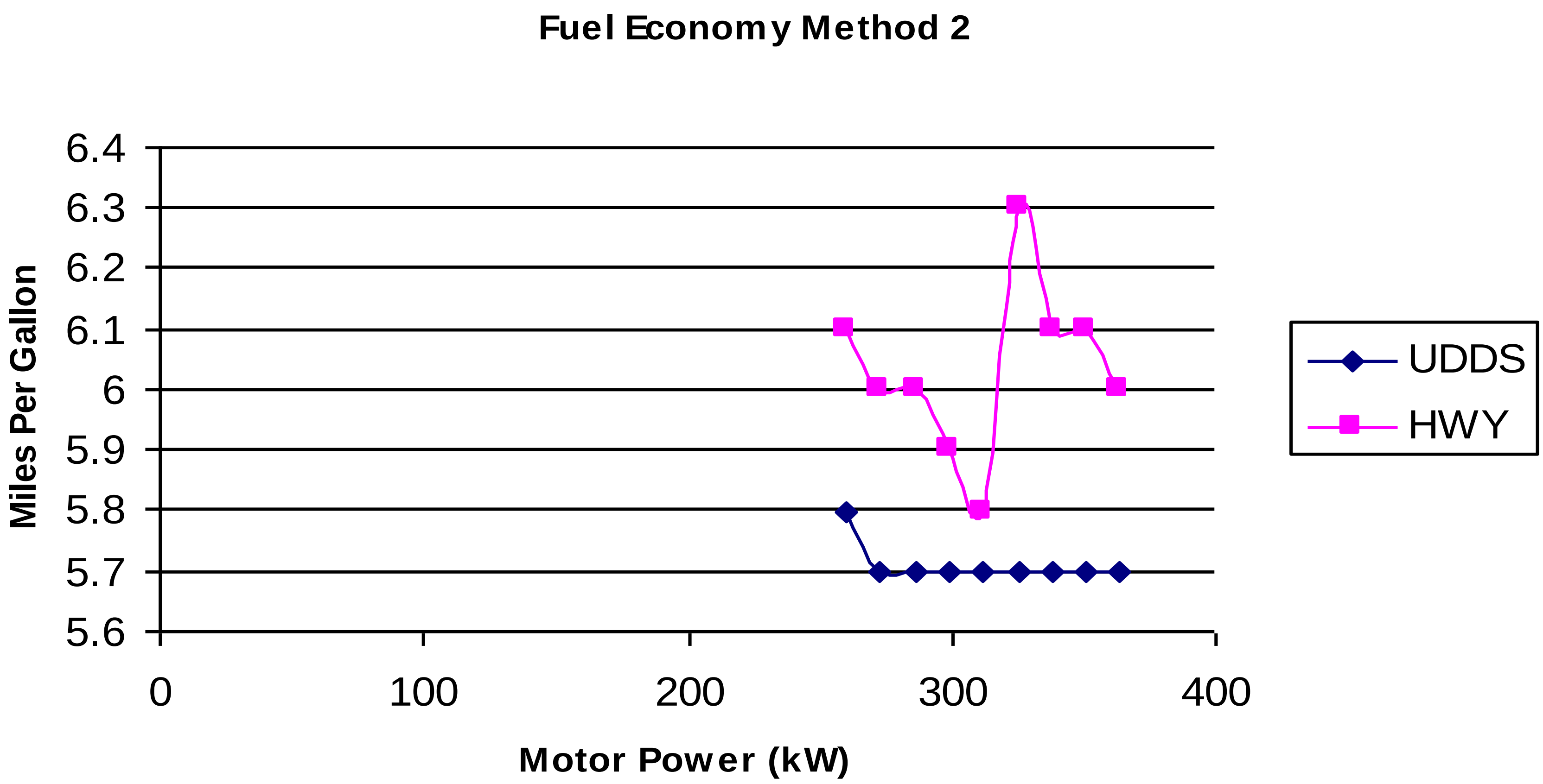


Figure 12: Variation in miles per gallon (mpg) over the range of e

Hybrid VS. Conventional

					Fuel Economy [mpg]	
	HF	0-60 mph	¼ mi	Max Speed	City	Highway
Conventional	N/A	9.8s	17.9s	101.2 mph	9.90	14.3
Hybrid Method 1	0.35	14.1s	19.6s	96.5 mph	21.6	17.6
Hybrid Method 2	0.20	31.6s	23.8s	72.2 mph	5.70	6.30

Table 14

Conclusion:

Fuel economy of the hybridized Series Hummer H2 increased for Method 1 and decreased for Method 2. Performance decreased for both methods when compared with conventional values.

Hybrid Electric Bus Systems:

Research and Simulations

Presenter: **Mahdi Mohammad**
Team Member: Ali Naqvi

Simulation Method

- Varying Motor Power
  - Motor power was increased from 0% to 70% of 150kW in increments of 5%

Fuel Economy Results

- Best MPG was obtained when the motor was scaled to 53kW (35%) with 50 battery modules and HF = 0.35

HF	UDDS	HWY
0.35	5.90	7.20

Table 15

Fuel Economy Chart

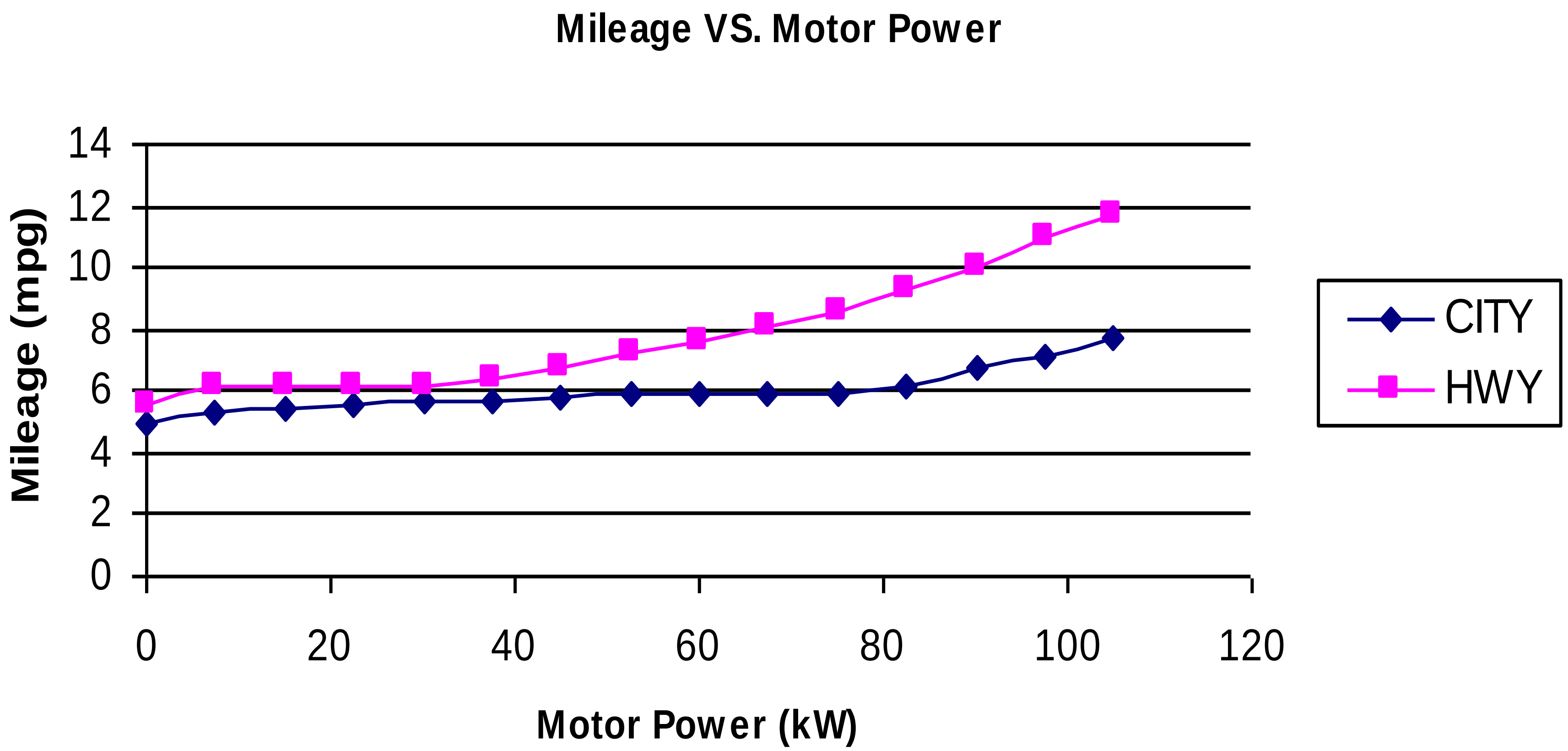


Figure 13: Variation in miles per gallon (mpg) over the range of en

Hybrid VS. Conventional

Vehicle Type	HF	CITY MPG	HWY MPG
Conventional	-	4.9	5.5
Hybrid	0.35	5.9	7.2
% IMPROVEMENT	-	20%	31%

Table 16

Conclusion:

The performance of the hybridized electric BUS quite increased when compared with

conventional values.

Future Work and Conclusion
Ipro 326 – Fall 2004

Presenter: **SADIA SADIQ**
[Team Leader]

Tasks Accomplished

- Hybrid HMMWV M1097 A2 Research and Simulation:

		Optimal HF
PARALLEL:	Method 1	0.50
	Method 2	0.40
SERIES:	Method 1	0.20
	Method 2	0.05

Table 17

- Hybrid HUMMER H2 Research and Simulation:

		Optimal HF
PARALLEL:	Method 1	0.05
	Method 2	0.21
SERIES:	Method 1	0.35
	Method 2	0.20

Table 18

Future Work

- Next steps to propel this IPRO include:
  - Determine optimum HF for parallel and series configurations of BRAND NEW Hummer H3, and compare results with values obtained for current H2.
  - Continue research on the Hybrid Electric Bus System, and work on its practical implementation by the end of the next year, 2005.
  - Optimize the Control Strategy utilized in this project.

Any Questions?

Don’t forget to check us out at: **http://www.iit.edu/~ipro326**

Thank You.