OPTIMAL DESIGN OF A RENEWABLE ENERGY SYSTEM FOR AN OFF-GRID DESALINATION FACILITY ON THE NAVAJO NATION IN THE UNITED STATES

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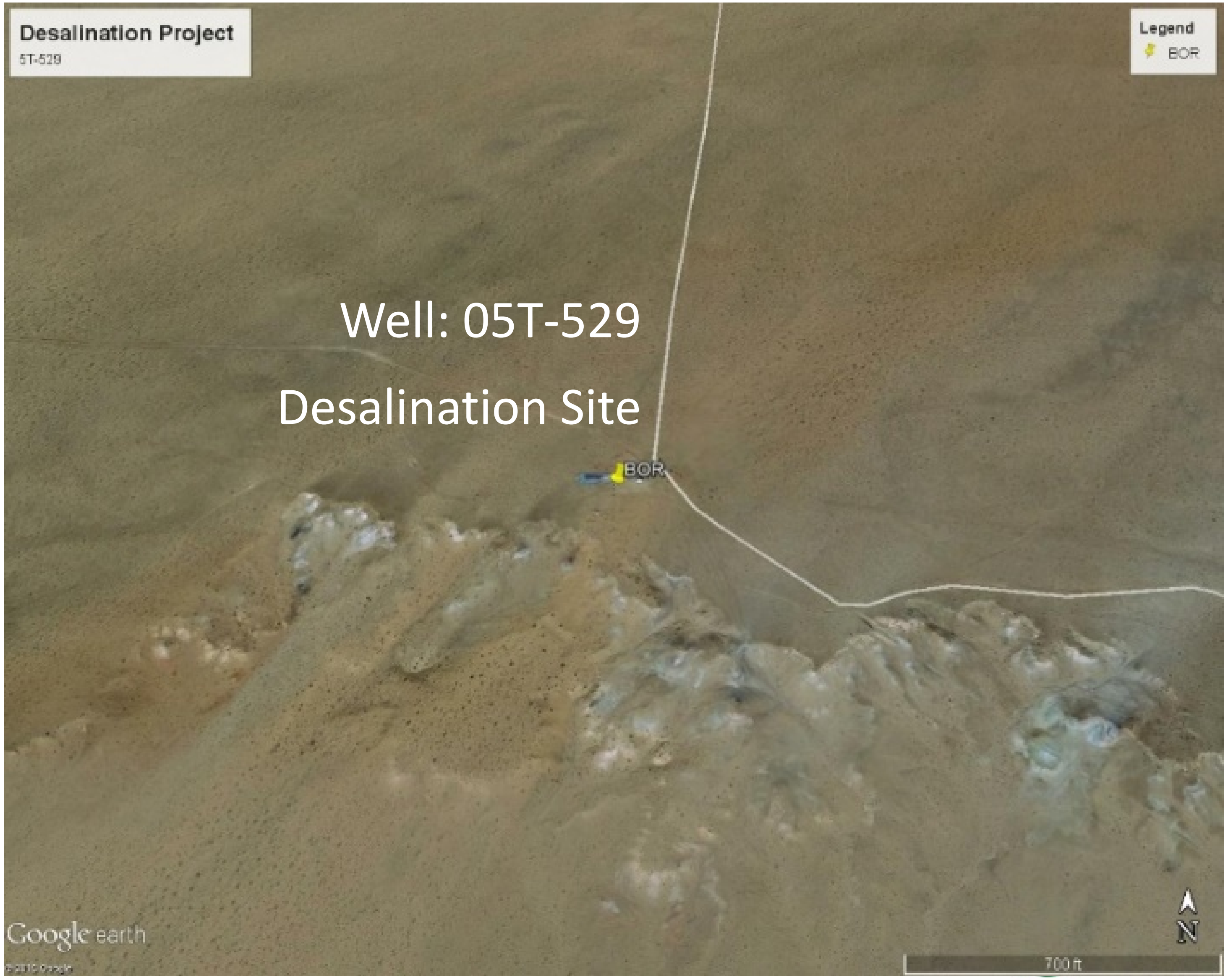
MAY 22-23, 2019
4TH INTERNATIONAL HYBRID POWER SYSTEMS WORKSHOP
CRETE, GREECE

ENERGY AND COMPUTATIONAL MODELING LAB

OUTLINE

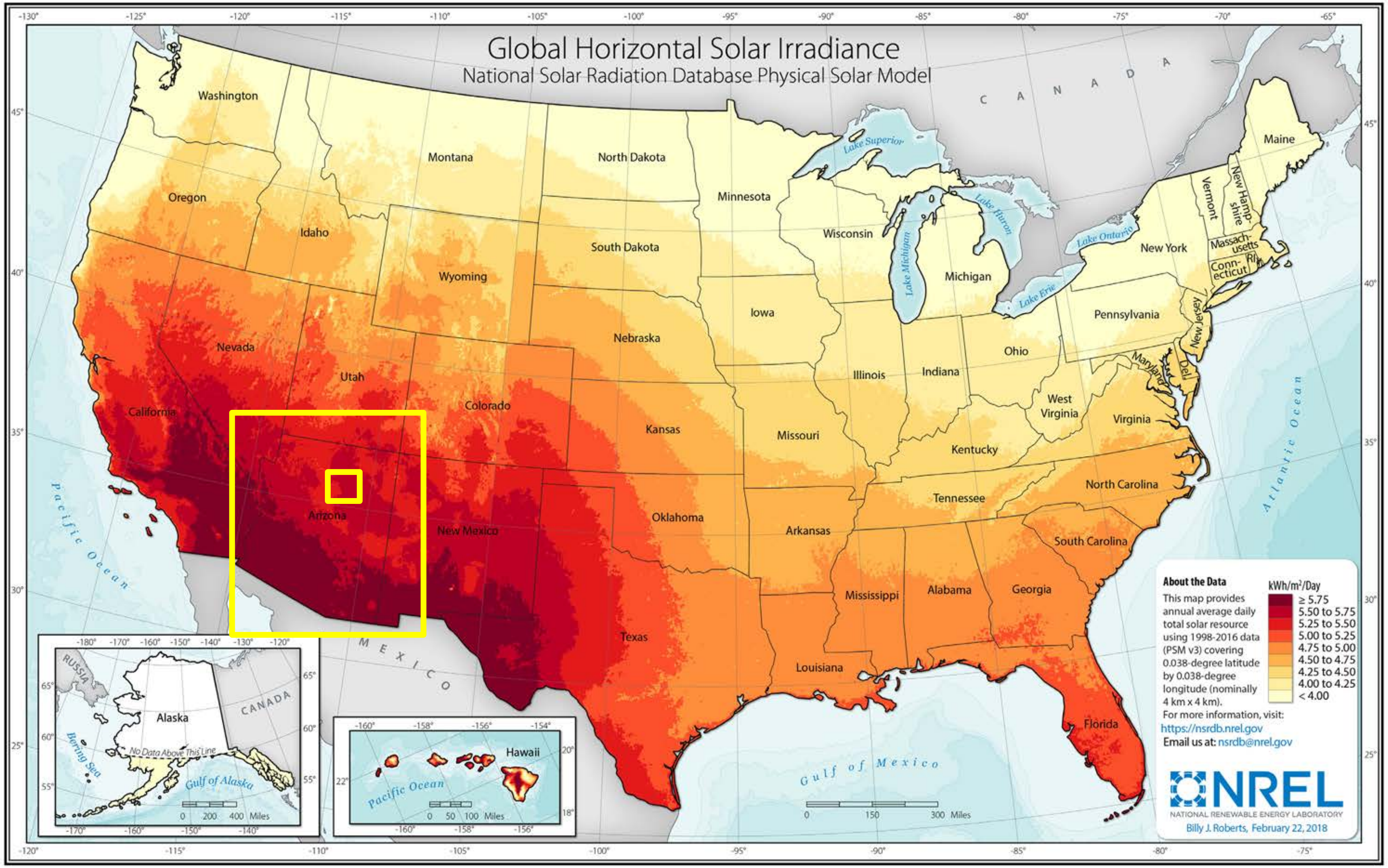
- Background
- Objectives
- RE system configuration and simulation
- Cost function
- Genetic Algorithm
- Results
- Conclusions



LOCATION

NAVAJO NATION

ARIZONA, USA



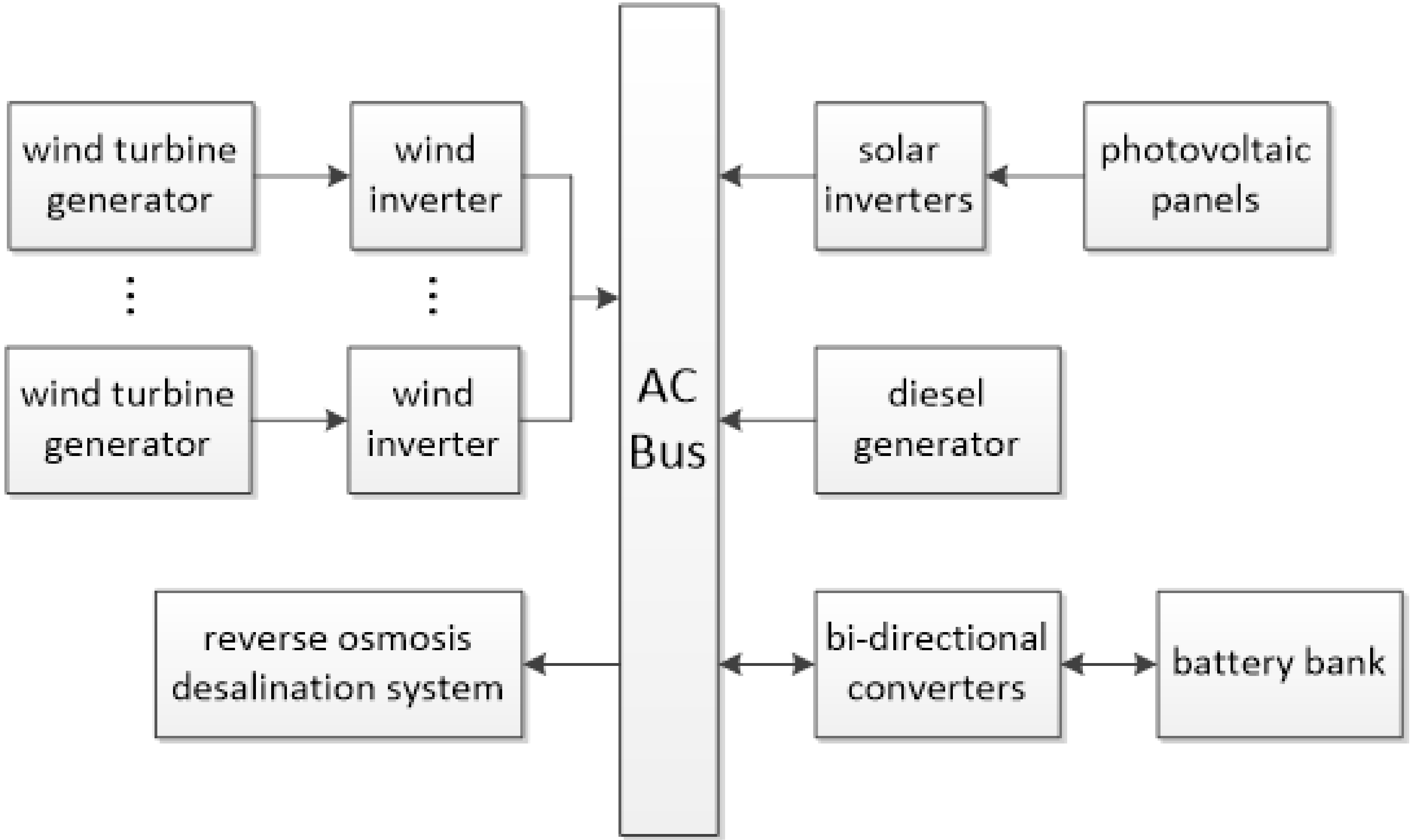
OFF-GRID WATER DESALINATION

- ~18,000 off-grid residents on the Navajo Nation
- Lack access to reliable electricity and potable water
- Cost to haul water ~ 3 US$ to 10 US$ per 0.38 m^3 (100 gal)
- Cost in nearby Flagstaff, AZ ~0.39 US$ per 0.38 m^3 (100 gal)

- Overarching goal:

  Rural, off-grid water well with desalination at a lower cost
- Technology choice: Reverse osmosis (RO) desalination

RENEWABLE ENERGY POWERED RO



COST FUNCTIONS

- Minimize the levelized cost of energy (LCOE) \$/kWh

$$LCOE = \sum_{j=1}^{n} \frac{I_{\mathrm{P},j} + M_{\mathrm{P},j} + F_{\mathrm{P},j}}{(1+r)^j} \Bigg/ \sum_{j=1}^{n} \frac{E_j}{(1+r)^j}$$

- Minimize the levelized cost of water (LCOW) \$/gallon

$$LCOW = \sum_{j=1}^{n} \frac{\left(I_{\mathrm{P},j} + M_{\mathrm{P},j} + F_{\mathrm{P},j}\right) + \left(I_{\mathrm{RO},j} + M_{\mathrm{RO},j}\right) + \left(I_{\mathrm{tank},j} + M_{\mathrm{tank},j}\right)}{(1+r)^j} \Bigg/ \sum_{j=1}^{n} \frac{Q_{\mathrm{W},j}}{(1+r)^j}$$

- Discount rate, $r=3\%$ Project lifetime, $n=10$ *years*

RENEWABLE ENERGY SYSTEM SIMULATION

- Renewable energy data: TMY3 (Typical Meteorological Year version 3)
- Solar Photovoltaic (PV) panels
  - Hay-Davies-Klucher-Reindl anisotropic model
  - Fixed-axis, zero-azimuth, titled from 0° (horizontal) to 90° (vertical, facing south)
  - 270 W panels, 3 in a string to equal 48V
- Wind turbine generator (WTG)
  - Winslow TMY3 wind data at 10-m
  - 1/7th power law vertical wind shear, 30-m hub height
  - Tumo Int 1-kW, 2-kW, or 3-kW rating

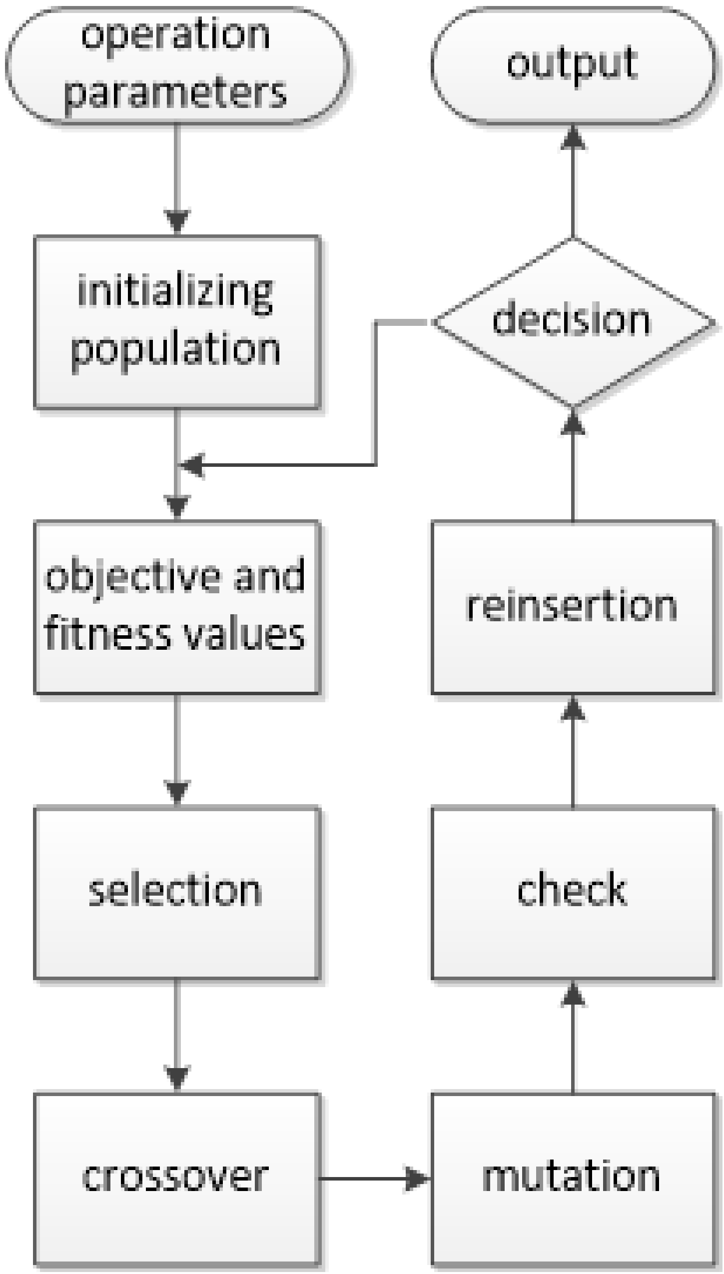
RENEWABLE ENERGY SYSTEM SIMULATION

- Valve-regulated lead-acid (VRLA) batteries
  - 2V batteries, 24 batteries per string
  - Amp-hour counting model, depth of discharge (DOD)-cycles to failure relations
- Diesel generator (DG)
  - 5 kW Cummins Onan QD, runs at 50% to 75% capacity
  - Charges batteries and serves load while running
- Dispatch - DG runs if insufficient RE for load, and battery state-of-charge SOC < 50%
- Viable RE systems must serve load, so loss of power supply probability (LPSP) = 0. RO Desalination 2.366 kW constant supply.

GENETIC ALGORITHM

$$population =$$

$$\begin{bmatrix} g_{1,1} & g_{1,2} & \cdots & g_{1,L_{ind}} \\ g_{2,1} & g_{2,2} & \cdots & g_{2,L_{ind}} \\ \cdot & \cdot & \cdots & \cdot \\ g_{N_{ind},1} & g_{N_{ind},2} & \cdots & g_{N_{ind},L_{ind}} \end{bmatrix}$$



DECISION VARIABLES (I.E. GENES)

- Decision variables … the "genes"

$$[Type_{WTG} \;\; N_{WTG} \;\; \beta \;\; N_{PV,p} \;\; N_{batt,p} \;\; N_{DG}]$$

$Type_{WTG}$ = Type I (1 kW), Type II (2 kW), or Type III (3 kW)

N_{WTG} = number of WTG

β = tilt angle of PV

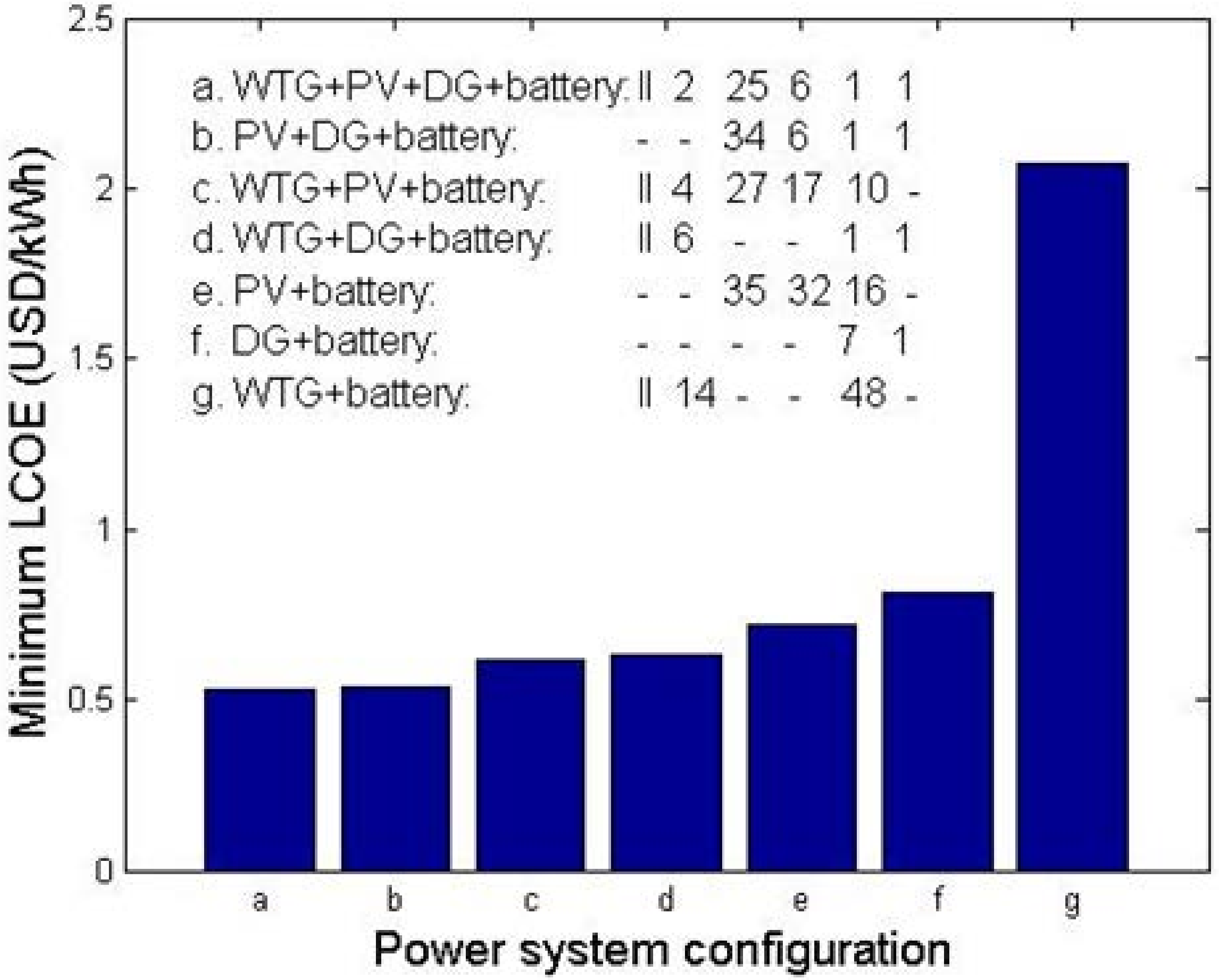
$N_{PV,p}$ = number of strings of PV

$N_{batt,p}$ = number of strings of batteries

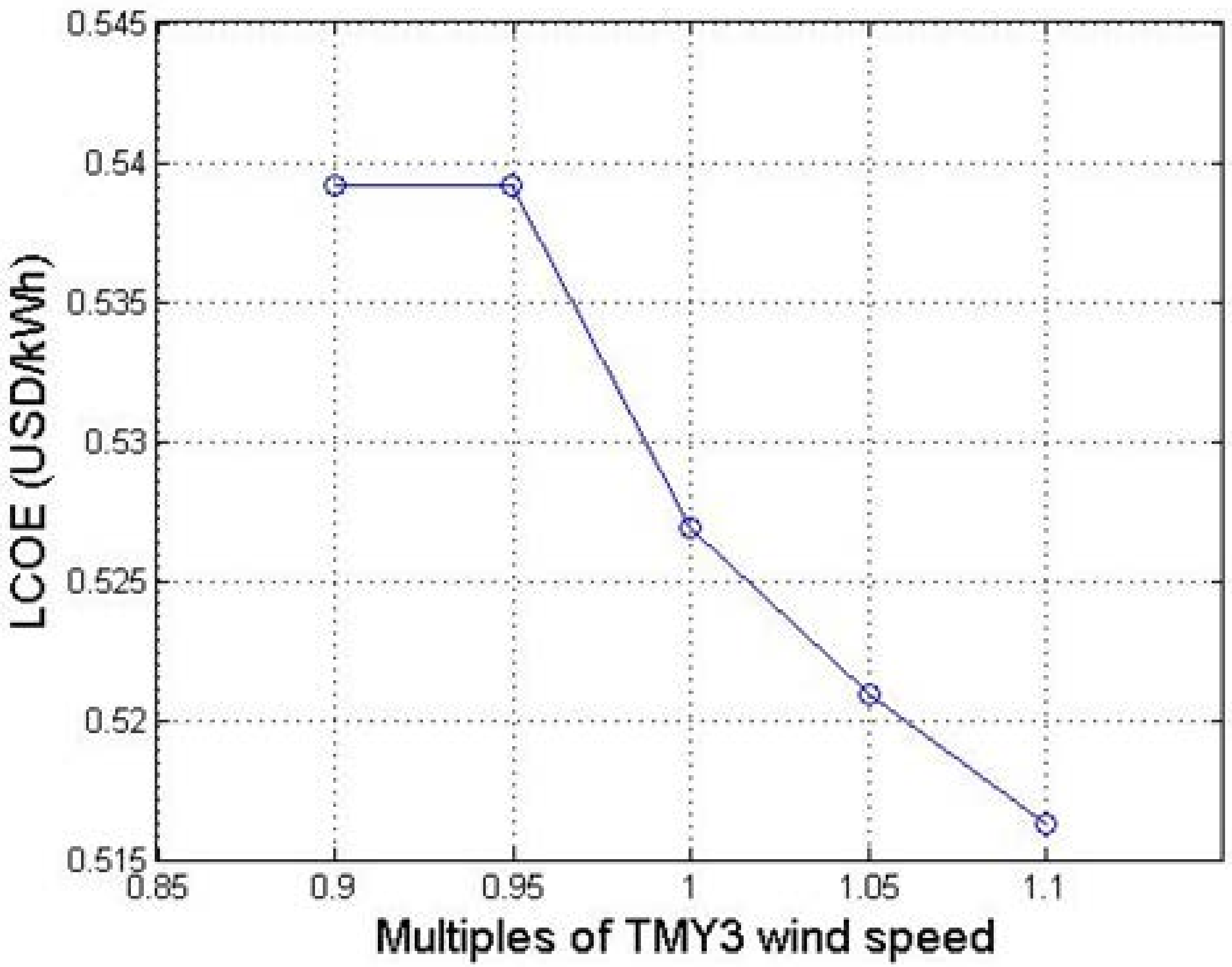
N_{DG} = number of DG (only one needed to cover load)

OPTIMIZATION RESULTS

[$Type_{WTG}$ N_{WTG} β $N_{PV,p}$ $N_{batt,p}$ N_{DG}]



SENSITIVITY TO WIND SPEED



CONCLUSIONS

- Genetic algorithm optimization
  - Minimum LCOE = 0.53 US$/kWh
  - Leads to a LCOW = 3.59 US$/$m^3$ or 1.36 US$ per 0.38 m^3 (100 gal)

    about 1/3 to 1/10 of current costs
  - The "more hybrid" the system, the lower the LCOE
  - Optimum system: WTG + PV + DG + Battery
- Optimum solution sensitive to wind speed
  - 5% decrease in mean wind speed leads to optimal design as PV + DG + Battery
  - Good estimate of wind speed is crucial

THANK YOU

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RE SYSTEM COMPONENTS

Energy System Component	Characteristics
Wind Turbine Generator: Tumo-Int [13]	
Type I: 1kW, 3-blade	$2,000
Type II: 2 kW, 3-blade	$4,000
Type 3: 3 kW, 5-blade	$5,000
Annual Maintenance	5% of capital
Lifetime	10 years
Wind Inverter: SMA Windy Boy [14,15]	$1/W
Efficiency	93%
Annual Maintenance	3% of capital
Lifetime	10 years
PV: SolarWorld SW270 Black Mono [16]	$290/panel
Max power	270 W
Module efficiency	16.1%
Annual Maintenance	3% of capital
Lifetime	20 years
Solar Inverter: SMA Sunny Boy [17,18]	$0.37/W
Efficiency	95%
Annual Maintenance	3% of capital
Lifetime	10 years

Energy System Component	Characteristics
DG: Cummins Onan QD 5 kW [9,10,11]	$8,135
Rated power	5 kW
Filters cost (change every 500 h)	$50
Cost of diesel	$0.86/L
Annual Maintenance	5% of capital
Lifetime	10,000 h
VRLA Batt: Enersys PowerSafe OPzV [19,20]	$300/kWh
Rated capacity	200 Ah, 2V
Roundtrip efficiency	85%
Annual Maintenance	3% of capital
Lifetime - determined via lifetime curves [21,22]	
Bi-dir. Conv. (SMA Sunny Island) [23]	$0.7/W
Inverter efficiency	94.5%
Rectifier efficiency	98%
Annual Maintenance	3% of capital
Lifetime	10 years

COMPARISON OF SIMULATION TO HOMER

	Homer	Simulation program	Deviation from Homer (%)
PV (kWh/y)	10,582	10,306	-2.6
WTG (kWh/y)	12,001	11,124	-7.3
DG (kWh/y)	7,974	7,995	0.3
DG operation hour (Hour/y)	2,130	2,132	0.1
Diesel consumption (L/y)	3,941	4,037	2.4
Battery Ah throughput (kWh/y)	4,486	4,415	-1.6
*PV and wind energy generated was measured on the AC bus.			