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Optimal Placement of Hybrid PV-Wind Systems Using Genetic Algorithm

Overview

- 1- Introduction
- 2- Hybrid PV-Wind System (HPWS)
- 3- System Structure and Modeling
- 4- System Design and GA Optimization
- Conclusion

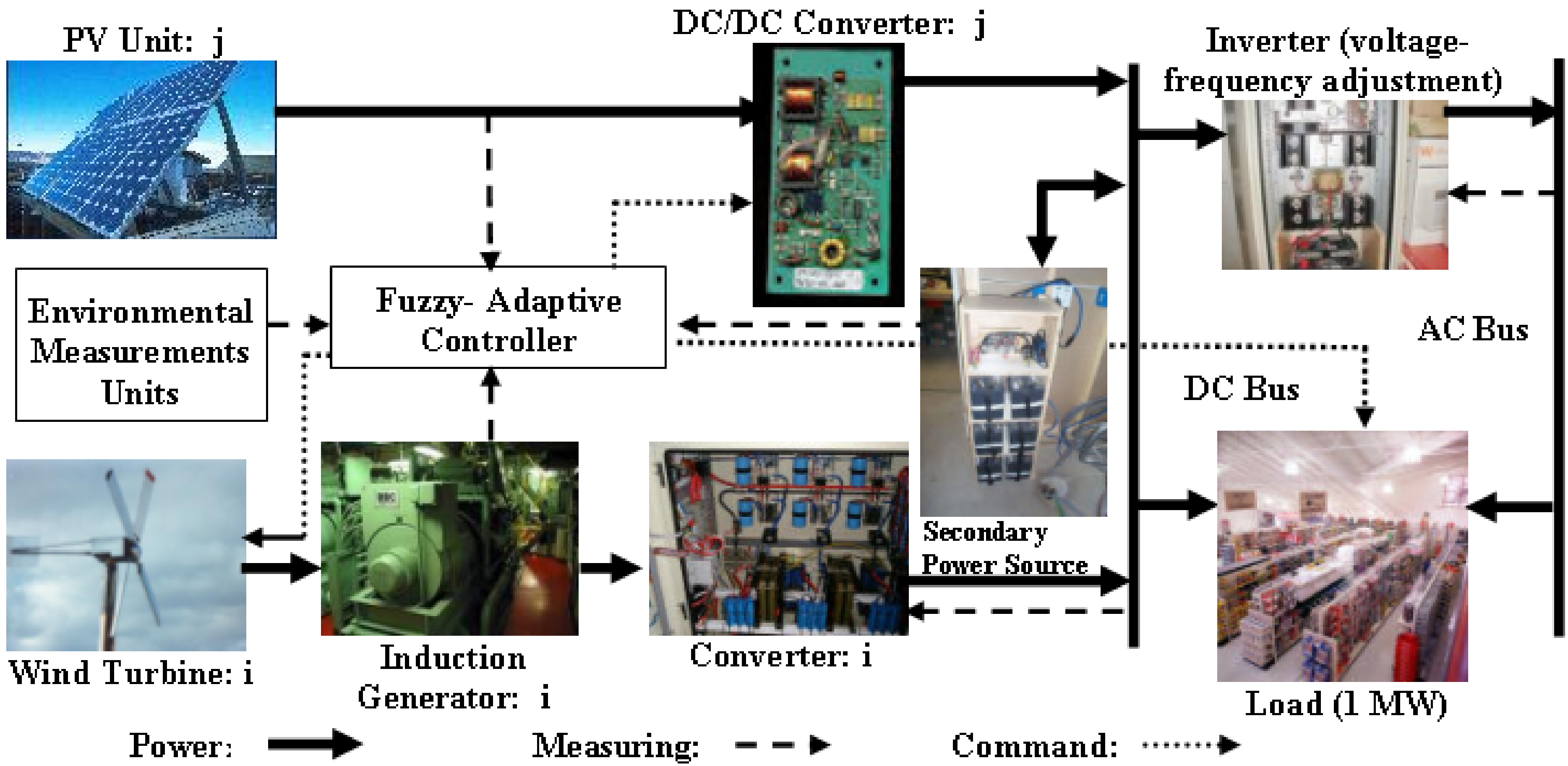
1- Introduction

- Rapid consumption of fossil energy → Renewable sources are replacing them in many applications including smart grids.
- Main drawbacks of renewable sources are high initial cost, availability and reliability
- This paper- hybrid PV-wind system (HPWS) with:
  - Battery storage (to improve reliability)
  - MPPT and blade angle pitch control BAPC (to increase efficiency)
  - Optimal locations of PV and wind units
  - Optimal unit sizing

GA is used to find the best location and ratio of wind/solar contributions for a 1MVA HPWS within 256 candidate locations in USA.

2- Hybrid PV-Wind System

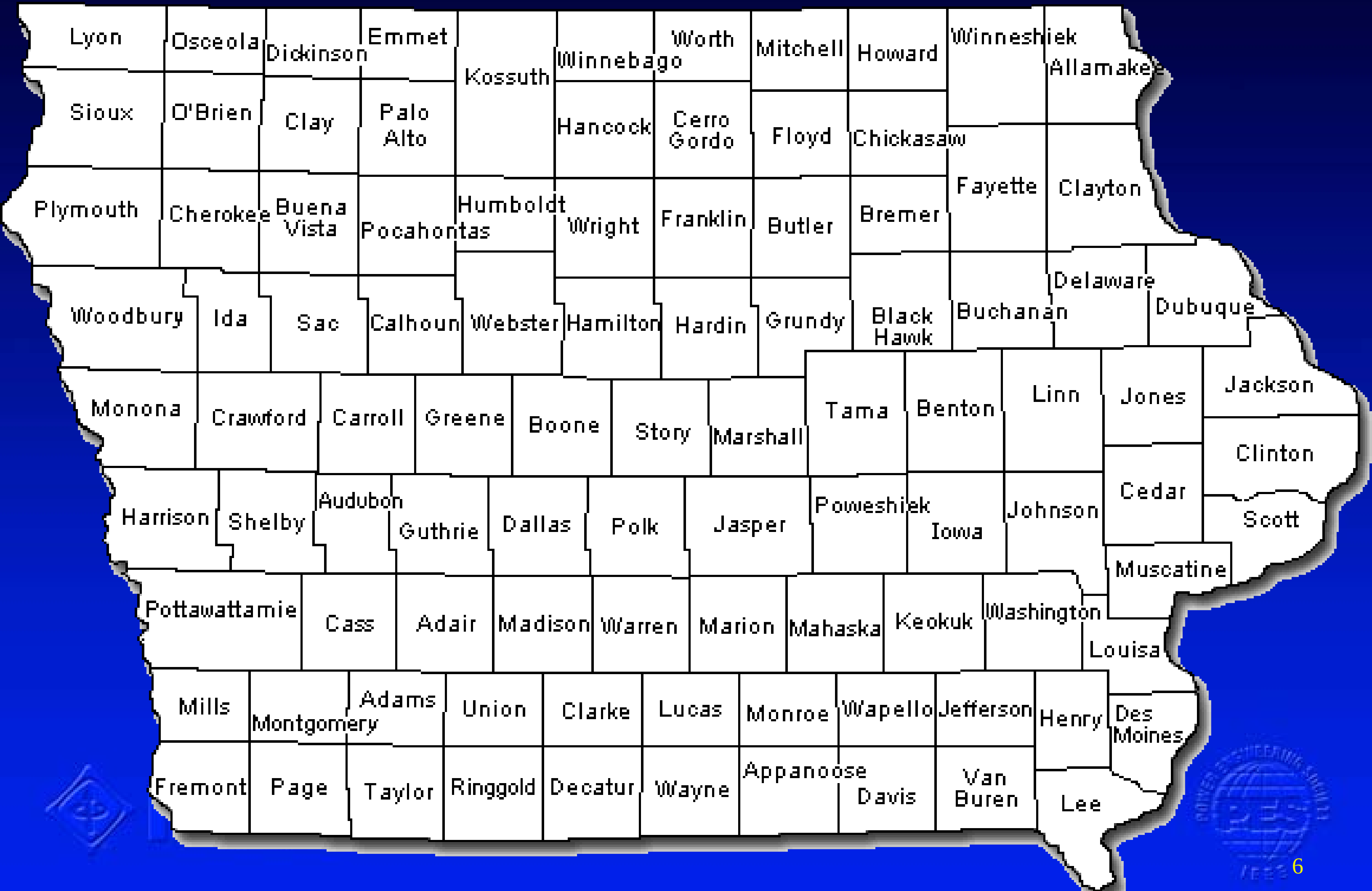
- **Overall block diagram:**



The Hybrid PV-Wind System includes:

- Induction generator (robustness, low cost, low maintenance and greater power-weight ratio)
- VMPPT for PV (DC/DC converter)
- BAPC of wind turbines
- Three-phase bridge rectifier
- AC bus (to facilitate system application)
- Secondary power source (for excessive and emergency loading conditions)
- Fuzzy- adaptive controller and synchronization (not discussed in this paper)

HPWS Locations Considered (Statistical Information Collected by Iowa Energy Center, www.energy.iastate.edu):



3- System Structure and Modeling

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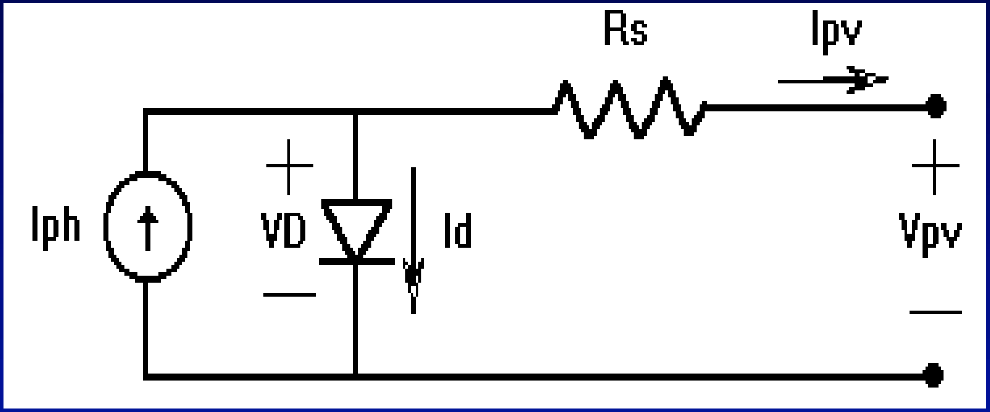
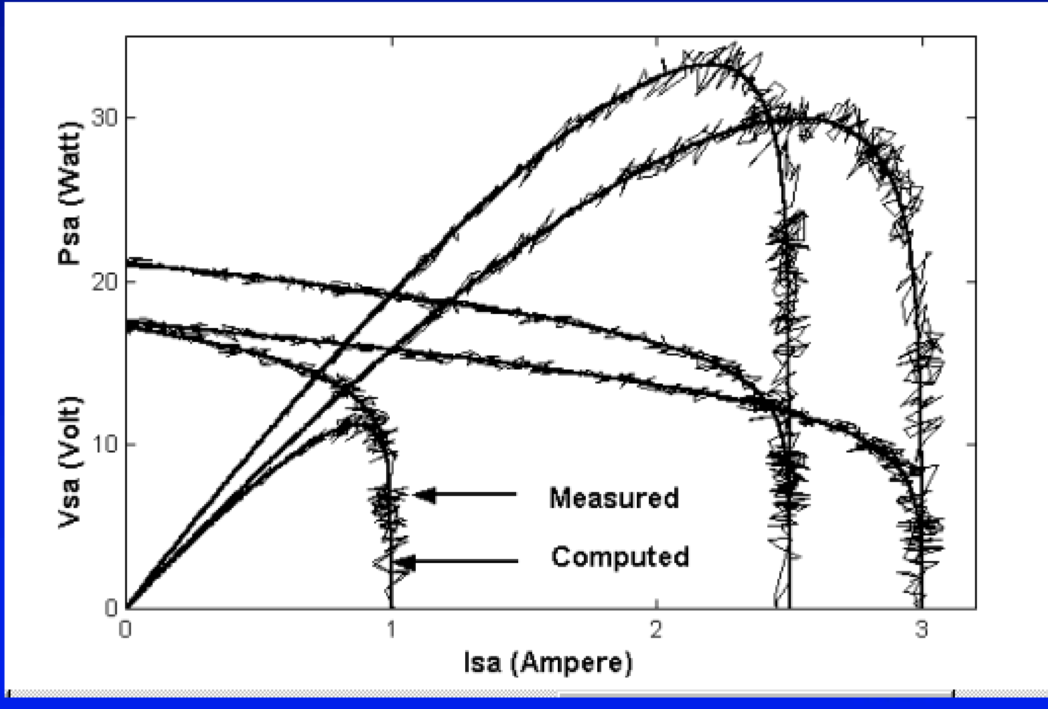


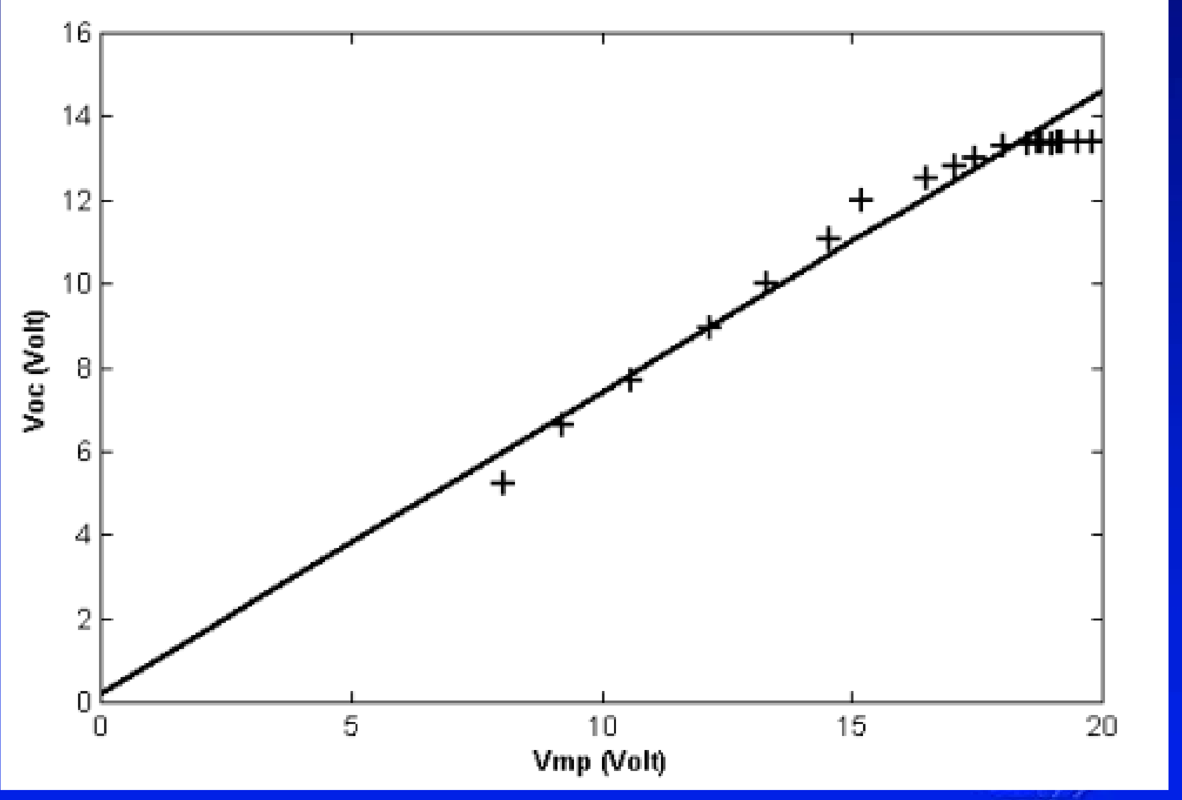
$$v_{pv} = \frac{N_S}{\lambda} \ln\left(\frac{N_P I_{ph} - i_{pv}}{N_P I_0} + 1\right) - \frac{N_S}{N_P} R_s i_{pv}$$

Measure and computed V-I Characteristics for one OFFC panel (T=25 at varying insolation levels).

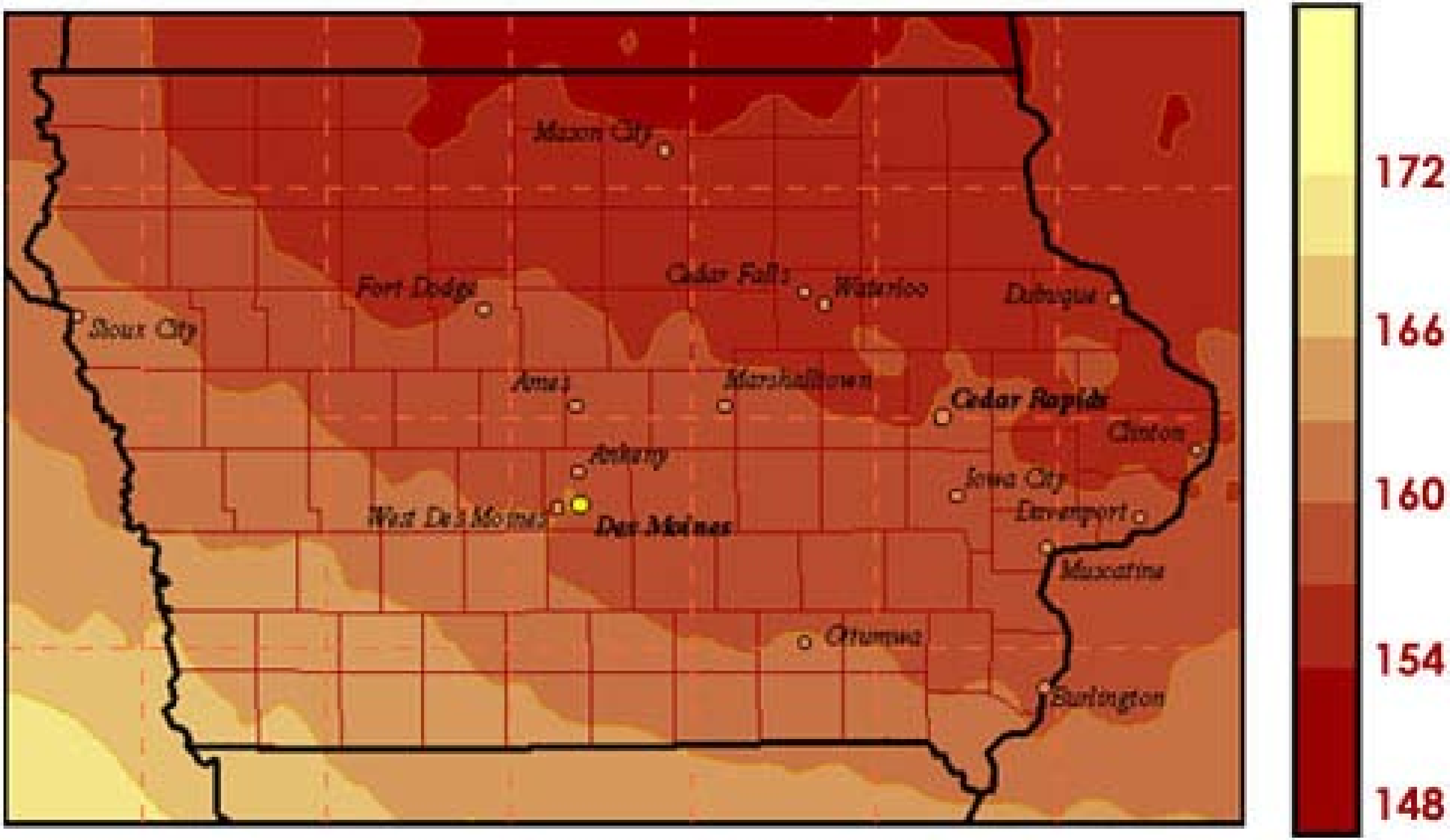


$$V_{mp} = f_{nonlinear}(V_{OC}) \cong f_{linear}(Voc) = M_v \times V_{OC}$$

Dependency of "cell voltages corresponding to maximum power to "cell open-circuit voltages" for one OFFC panel (T=25 at varying insolation levels).



Yearly Averaged Global Irradiance (Watt/sq.m)

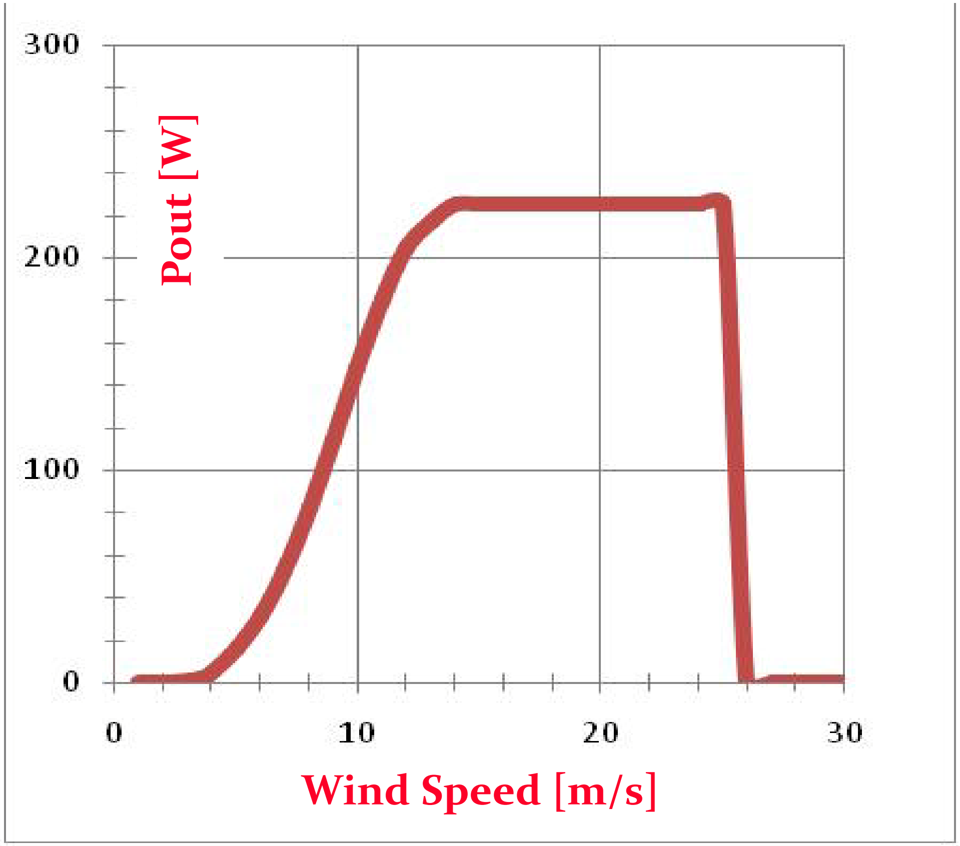


- # Wind Unit Modeling

Wind output power (Betz law):

$$P_W(v) = \begin{cases} [(v - v_c)/(v_r - v_c)]P_r & v_c \le v \le v_r \\ P_r & v_r \le v \le v_f \\ 0 & otherwise \end{cases}$$

where V_r, P_r, V_r and V_f are turbines nominal speed, power, low cutoff speed and high cutoff speed, respectively.



- **Wind Unit Modeling (continue)**

Average power produced by each wind-turbine:

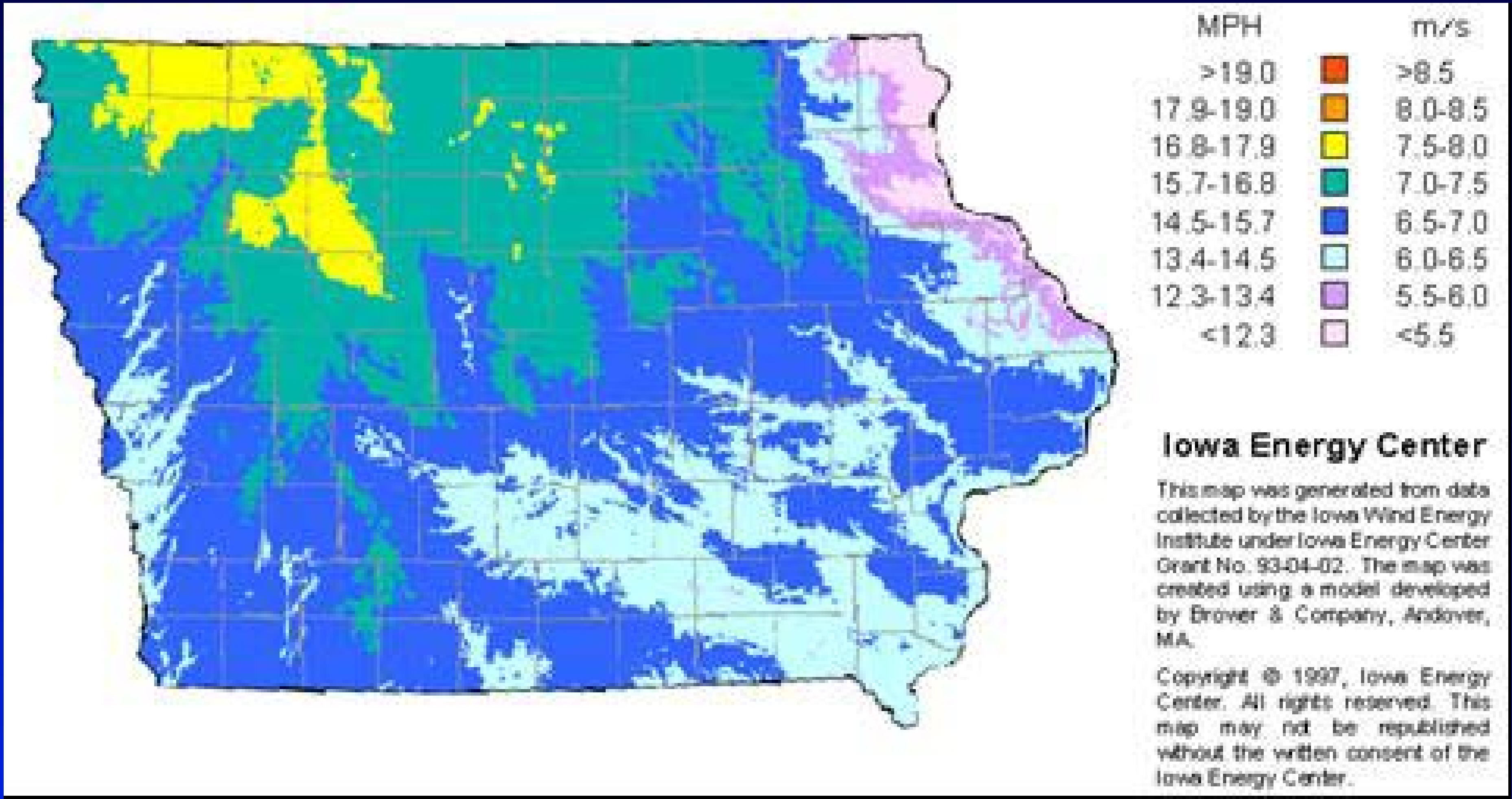
$$P_{W,avg} = \int_0^{\infty} P_w \, f(v) \, dv$$

Where f(v) is the Weibull density function:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] (k > 0, v > 0, c > 0)$$

where v= wind speed, c= gauge parameter =7.01m/s and k= shape parameter =1.99m/s. c and k are estimated based on the statistical computations

• Wind Unit Modeling (continue)



- **Wind Unit Modeling (continue)**

Technical properties of the Wind unit

Manufacture, type	Vestas225-29, lateral axes
Rated power	225 KW (in rated speed)
Rated, cut-in and cut-out speeds	14.5, 2.3, 39.3 (m/s)
Output	480 VAC/3-phase/60 HZ
Statistic function: output power (KW) – mean wind speed(m/s)	$= 21.09\ v_r - 79.38$

With:

-- AC & DC loads; $P_{load-ave}$= 1 MW

-- P_{PV-ave}= 40 kW/unit

-- $P_{wind-ave}$= 68.46 kW/unit,

The load may be supplied by:

1) $n_{wind-max} = 15$

2) $n_{PV-max} = 25$

3) **HPWS (optimum # of PV and wind)**

4- System Design & GA Optimization

Cost Function:

$$CF = \min_{l=1}^{L_{max}} (CF^l) = \min_{l=1}^{L_{max}} CF_c^l \times \frac{\min(CF_{nc}^l)}{\min(CF_c^l)}$$

$$CF_c^l = \frac{CF_{nc}^l(n_{pv}) * Lops^l(n_{pv})}{\left\| Lops^l(n_{pv}) \right\|}$$

$$CF_{nc}^l = (CF_{PV}^l + CF_{Wind}^l + CF_{Sec}^l - CF_{Add.}^l)$$

$$CF_{PV}^l = \frac{n_{PV}^l \times k_{PV}(P_{Avg-PV}^l)}{(\eta_{DC/DC})(k_{Acc-PV}^l)},$$

$$CF_{Wind}^l = \frac{n_{Wind}^l \times k_{Wind}^l(P_{Avg-Wind}^l)}{(\eta_{AC/DC})(k_{Acc-Wind}^l)},$$

$$CF_{Sec.}^l = k_{Sec} \times C_{Sec-Max}^l \times \eta_{Ch.-DisCh} / t,$$

$$CF_{Add}^l = k_{Add} \times p_{Add}^l, \quad l = 1, \dots L_{Max}.$$

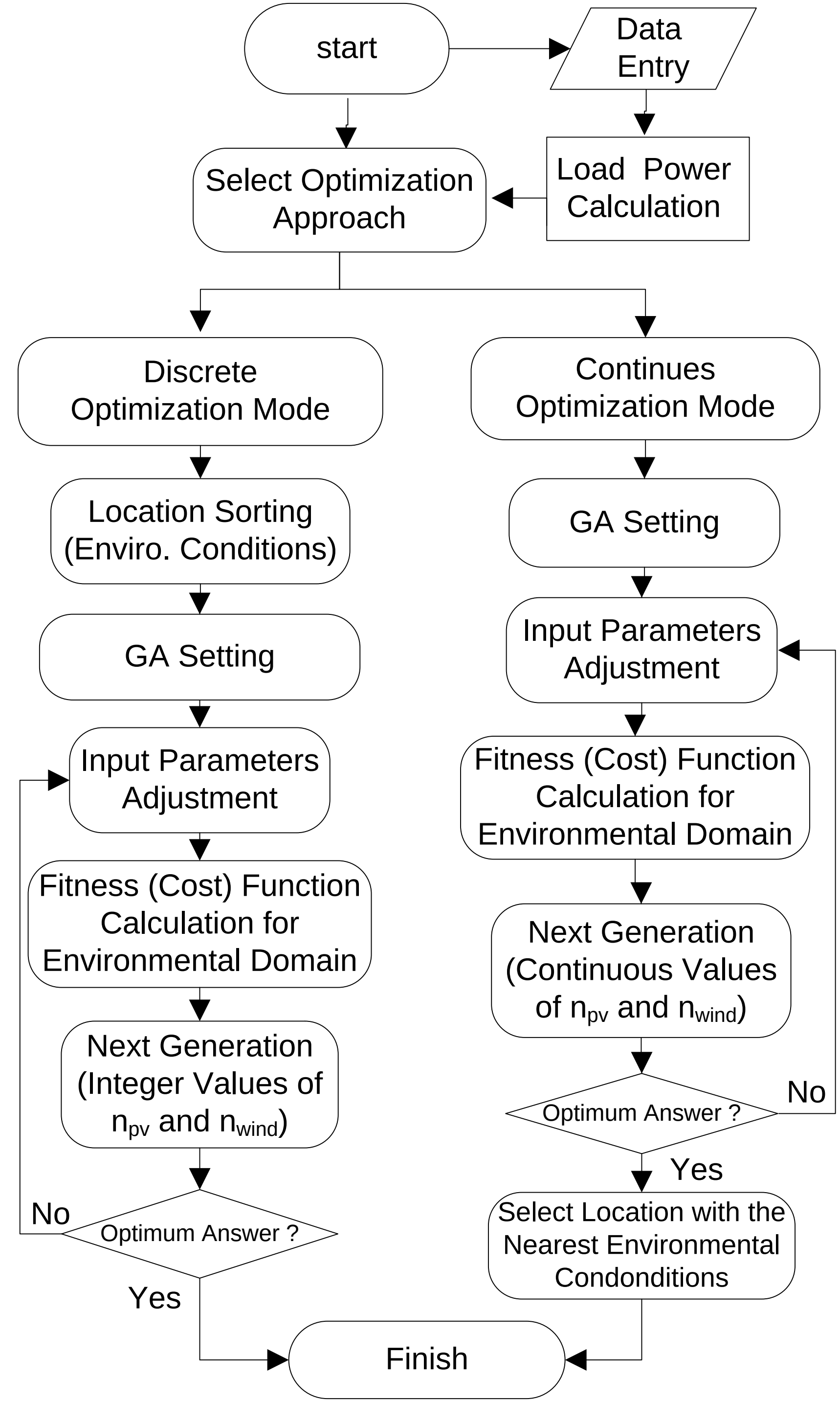
Lopsl= probability of load shading at location l .

CFnc* & *CFc= total costs without/with load shading.

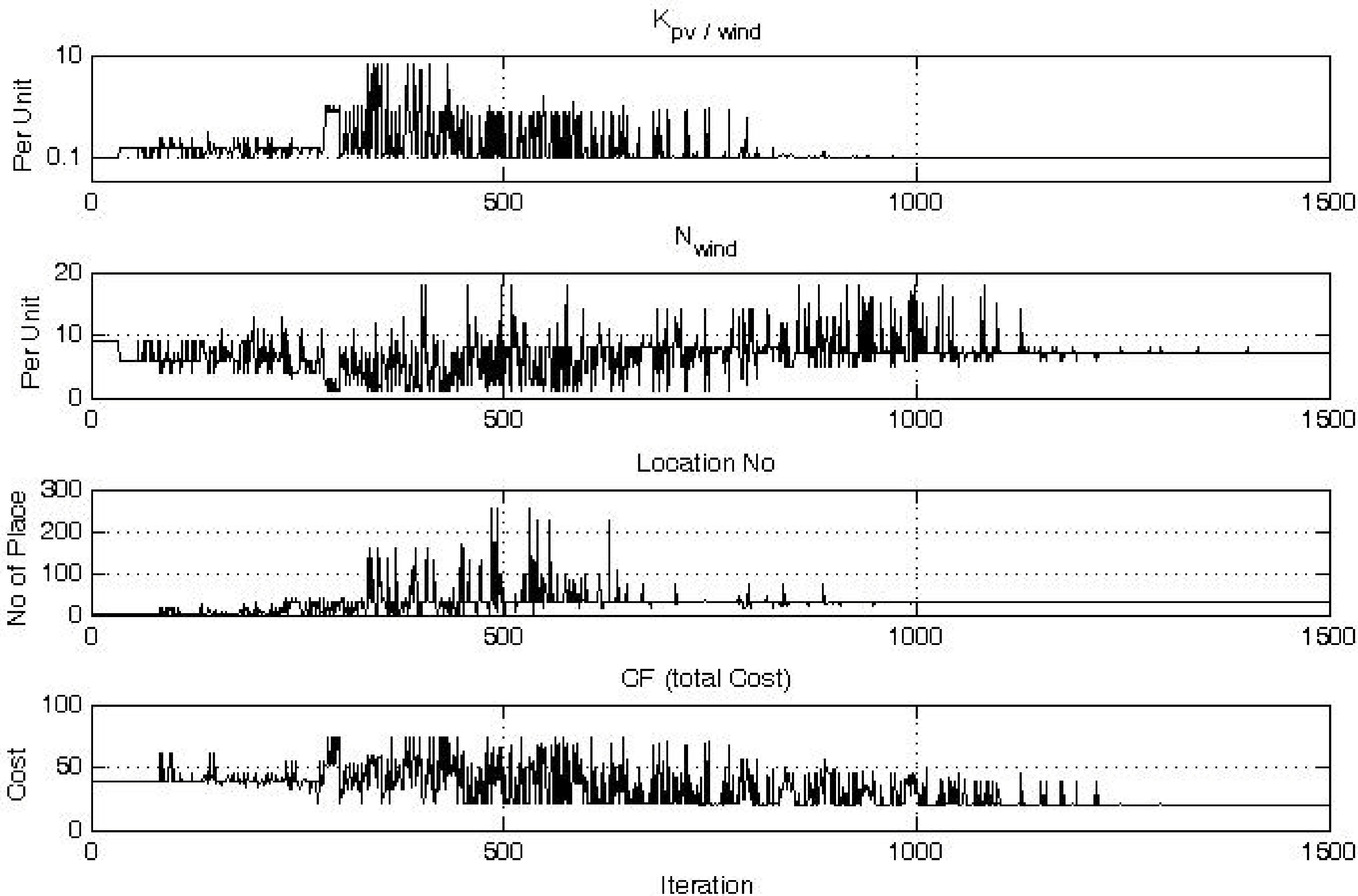
CFpv* & *CFwind= costs of one solar & one wind.

CFadd* & *CFsec= cost of additional-available power & secondary (battery) sys.

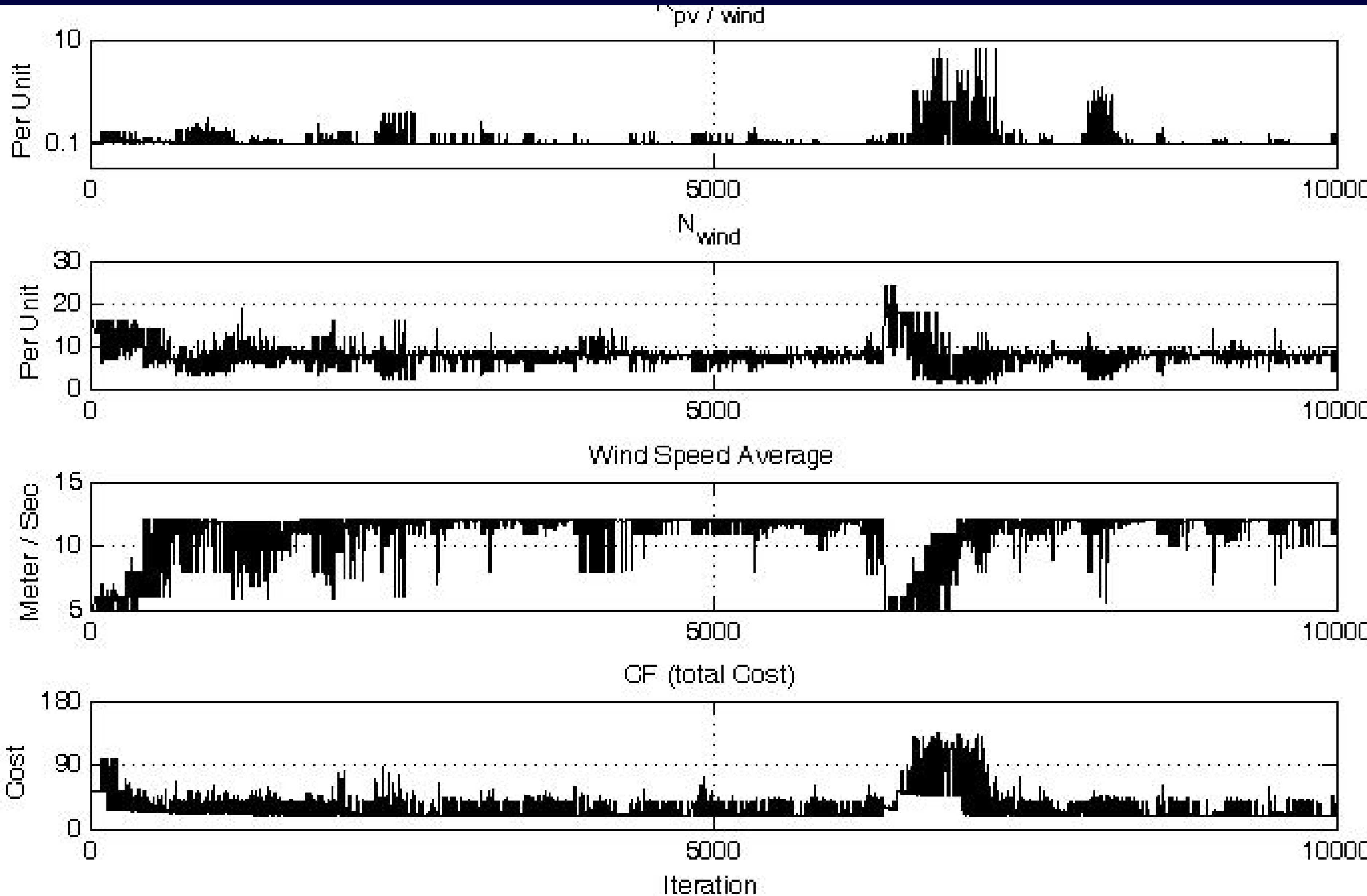
- # GA Optimization



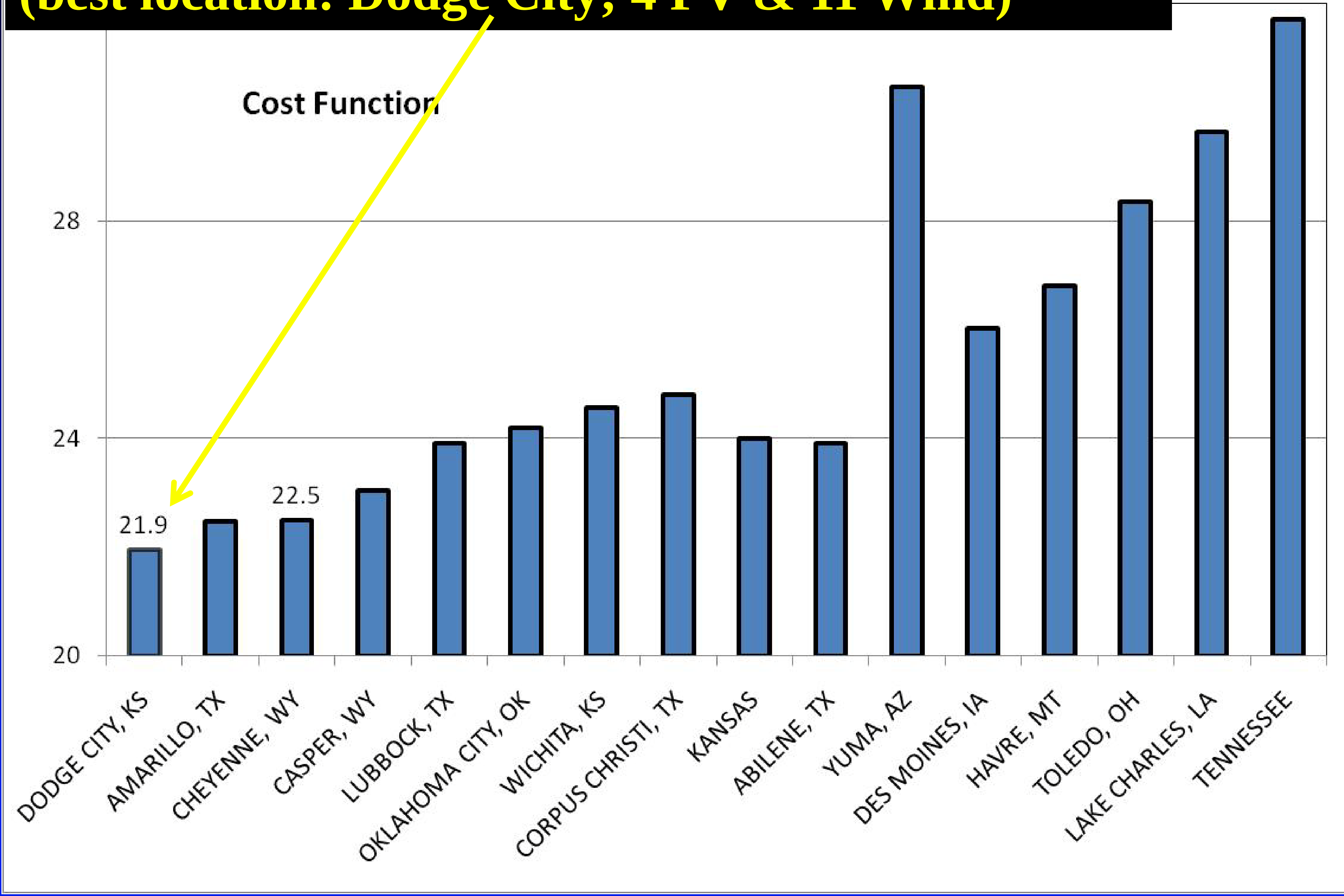
• GA Results (Discrete Mode)

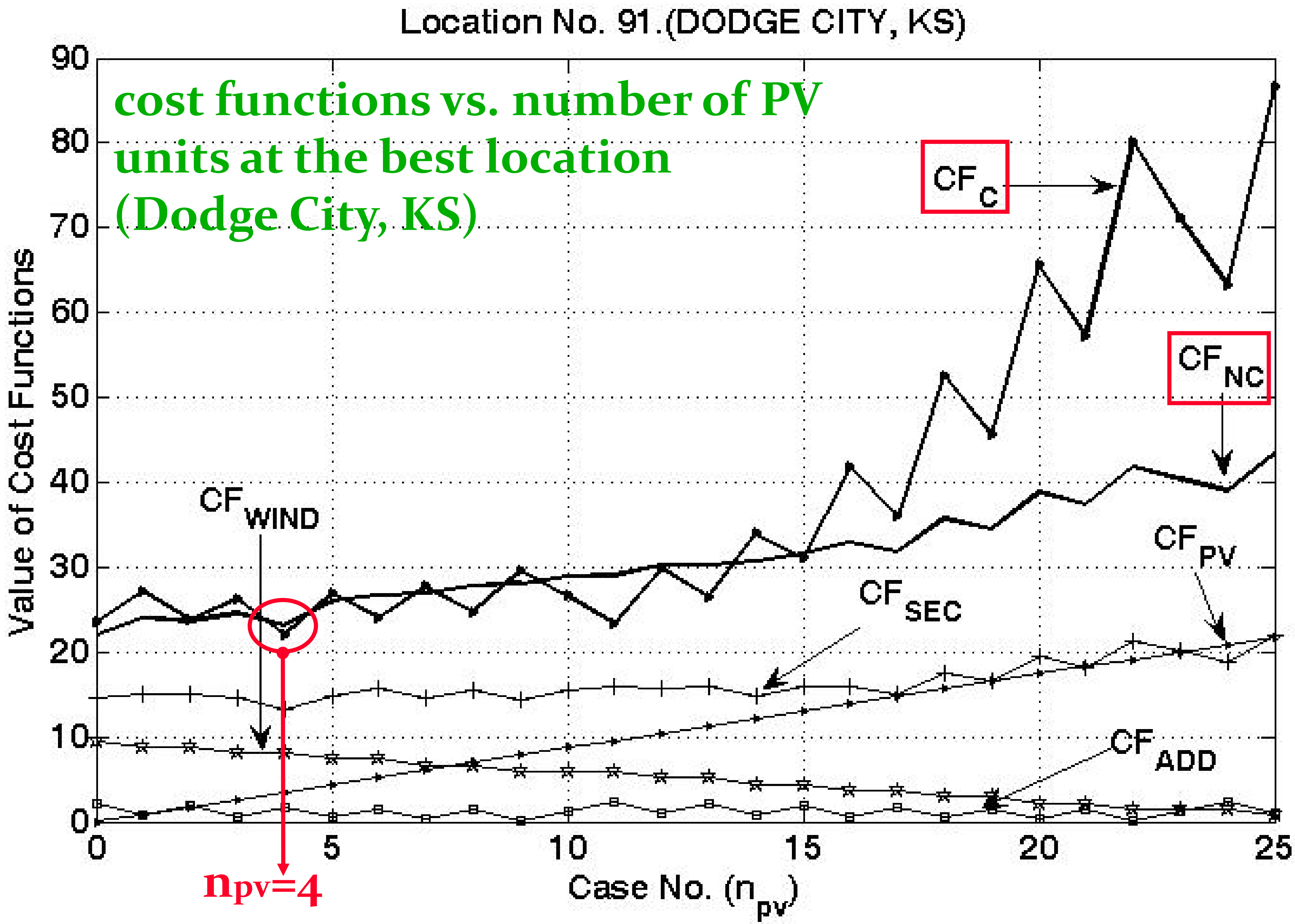


• GA Results (Continues Mode)



Computed cost functions for some typical locations (best location: Dodge City; 4 PV & 11 Wind)





Location No. 91.(DODGE CITY, KS)
cost functions vs. number of PV units at the best location (Dodge City, KS)
Value of Cost Functions
Case No. (n_{pv})
CF_C
CF_{NC}
CF_{WIND}
CF_{PV}
CF_{SEC}
CF_{ADD}
$n_{pv}=4$
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90

Recall:

CF_{nc} & CF_c *are* **total costs without/with load shading (at location l).**

$$CF_c^l = \frac{CF_{nc}^l(n_{pv}) * Lops^l(n_{pv})}{\left\| Lops^l(n_{pv}) \right\|}$$

$$CF_{nc}^l = (CF_{PV}^l + CF_{Wind}^l + CF_{Sec}^l - CF_{Add.}^l)$$

Conclusion

A hybrid PV-wind system is modeled that includes:

- MPPT of PV units and blade angle pitch control of wind turbines.

New cost function is defined and GA is used to find:

- best location of HPWS, number of PV & wind units (ratio of wind/solar power contributions).

$$CF^{l}_{Sec.} = k_{Sec} \times C^{l}_{Sec-Max} \times \eta_{Ch.-DisCh} / t,$$

$$CF^{l}_{Add} = k_{Add} \times p^{l}_{Add}, \quad l = 1, \ldots L_{Max}.$$

$$CF^{l}_{PV} = \frac{n^{l}_{PV} \times k_{PV}(P^{l}_{Avg-PV})}{(\eta_{DC/DC})(k^{l}_{Acc-PV})},$$

$$CF^{l}_{Wind} = \frac{n^{l}_{Wind} \times k^{l}_{Wind}(P^{l}_{Avg-Wind})}{(\eta_{AC/DC})(k^{l}_{Acc-Wind})},$$

t = operating time (hour),

l = location number,

k in numerators = statistical production cost (k_{Wind}=0.089, k_{PV}=0.225, k_{Sect}=350, k_{Add}=0.282),

k in denominators = statistical source accessibility expense,

n = number of each unit,

η = average converters efficiency ($\eta_{DC/DC}$=0.90, $\eta_{AC/DC}$=0.87),

$C_{Batt-Max}$ = maximum required battery capacity under all operating conditions,

P_{Add} = surplus produced power of each structure (positive energy balance) with usual electricity cost.