2017 Competition
Evaluating the Performance of Modern Heuristic Optimizers on Smart Grid Operation Problems

Test bed 1:
Stochastic OPF based active-reactive power dispatch

Sergio Rivera[1], Andres Romero[2], José Rueda[3], Kwang Y. Lee[4], István Erlich[5]

[1]Laboratorio de Metrología (LABE+i) and ElectroMagnetic Compatibility research group (EMC-UN), Department of Electrical Engineering, Universidad Nacional de Colombia, Bogotá, Colombia

[2]Instituto de Energía Eléctrica, Universidad Nacional de San Juan, San Juan, Argentina

[3]Department of Electrical Sustainable Energy, Delft University of Technology, Delft, Netherlands

[4]Department of Electrical and Computer Engineering, Baylor University, Waco, USA

[5]Electrical Power Systems, University Duisburg-Essen, Duisburg, Germany

srriverar@unal.edu.co, aromero@iee.unsj.edu.ar, j.l.ruedatorres@tudelft.nl, Kwang_Y_Lee@baylor.edu, istvan.erlich@uni-due.de

IEEE PES Power & Energy Society® IEEE

2014 competition

- OPTIMAL ACTIVE-REACTIVE POWER DISPATCH PROBLEM

$$C_{total} = \sum_{i=1}^{Nc} C_i(P_{s,i})$$

The conventional generators are assumed to have a quadratic cost function with $P_{s,i}$ as the scheduled power output of generator i; and α_i, β_i, γ_i as the cost coefficients of generator i:

$$C_i(P_{s,i}) = \alpha_i + \beta_i P_{s,i} + \gamma_i P_{s,i}^2$$

2017 competition, test bed 1

- OPTIMAL ACTIVE-REACTIVE POWER DISPATCH PROBLEM

Optimal Active-Reactive Power Dispatch (OARPD)

In the formulation proposed, the objective is set to minimize the expected value of the total generation cost (C_{total}):

$$\min \quad E[C_{total}]$$

where $E[*]$ denotes the expectation operator, given by the probability-weighted average of all possible values of a random variable.

2017 competition, test bed 1

- OPTIMAL ACTIVE-REACTIVE POWER DISPATCH PROBLEM

The total generation cost is given by:

$$C_{total} = \sum_{i=1}^{Nc} C_i(P_{s,i})$$

$$+\sum_{i=1}^{Nw} C_{w,i}(W_{s,i}) + \sum_{i=1}^{Nw} C_{w,u,i}(W_{s,i}, W_i) + \sum_{i=1}^{Nw} C_{w,o,i}(W_{s,i}, W_i)$$

IEEE PES Power & Energy Society®

2017 competition, test bed 1

- OPTIMAL ACTIVE-REACTIVE POWER DISPATCH PROBLEM

The cost of a wind power generator is divided into three components. The first component account to for the direct cost paid by the system operator to the owner of the wind generator

$$C_{w,i}(W_{s,i}) = c_{w,i} \cdot W_{s,i}$$

Factors for underestimation and overestimation of power availability are included in the formulation as the second and third components mentioned in the previous paragraph, due to the uncertainty of the wind power available at any given time.

$$C_{w,u,i}(W_{s,i}, W_i) = c_{w,u,i}(W_i - W_{s,i})$$

$$C_{w,o,i}(W_{s,i}, W_i) = c_{w,o,i}(W_{s,i} - W_i)$$

2017 competition, test bed 1

- Underestimated condition

The scheduled power (Ps_i) in the renewable generator i is lesser than the available real power (Pa_i), and there will be a cost for underestimate given by: $Cu=c_u(Pa_i-Ps_i)$ due to the total available power that is not used in the system (only it is used Ps_i). It would be a kind of power wasted, but in the real life could be considered as a power directed to an energy storage system with a related cost for using the system (c_u).

- Overestimated condition

The scheduled power (Ps_i) in the renewable generator i is bigger than the available real power (Pa_i), and there will be a cost for overestimate given by: $Co=c_o(Ps_i-Pa_i)$ due to the total available power is not enough to get the power to be scheduled in the system (Ps_i). In this case the network operator must turn on or request more power to another energy source with a related cost (c_o).

2017 competition, test bed 1

In order to solve the proposed formulation, several population based optimization algorithms are used; in this way the target function is subject to the following kind of constraints depending in how they are handled in the optimization algorithms:

2017 competition, test bed 1

1) Equality constraints considered with a power flow inside of the optimization algorithm

These constraints are given by the active power flow balance equations and the reactive power flow balance equations at all buses:

$$P_{gi} - P_{di} - v_i \sum_{j \in N_B} v_j (g_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) = 0$$

$$Q_{gi} - Q_{di} - v_i \sum_{j \in N_B} v_j (g_{ij} \sin\theta_{ij} + B_{ij} \cos\theta_{ij}) = 0$$

IEEE PES Power & Energy Society®

IEEE

2017 competition, test bed 1

2) *Inequality constraints related with the decision variables*

$$P_{s,i}^{\min} \le P_{s,i} \le P_{s,i}^{\max}, i \in N_g - 1$$

$$v_{gi}^{\min} \le v_{gi} \le v_{gi}^{\max}, i \in N_g$$

$$T_k^{\min} \le T_k \le T_k^{\max}, k \in N_T$$

$$Shunt_i = \begin{cases} 0 \\ \text{or} \\ defaultShunt_i \end{cases}, i \in N_{CD}$$

where N_g is the number of buses with conventional generators; N_T is the number of branches with transformers with on line tap changers. $defaultShunt_i$ is the reactive power injected at nominal tension by the compensation device in bus i, and N_{CD} is the number of compensation devices.

2017 competition, test bed 1

3) Inequality constraints related with the fitness function inside of the optimization algorithm

These constraints are given by the reactive power generation limit at each generator bus, the voltage magnitude limit at each load bus, and the power flow limit constraint of each transmission line:

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max}, i \in N_g$$

$$v_{loadi}^{\min} \le v_{loadi} \le v_{loadi}^{\max}, i \in N_{LB}$$

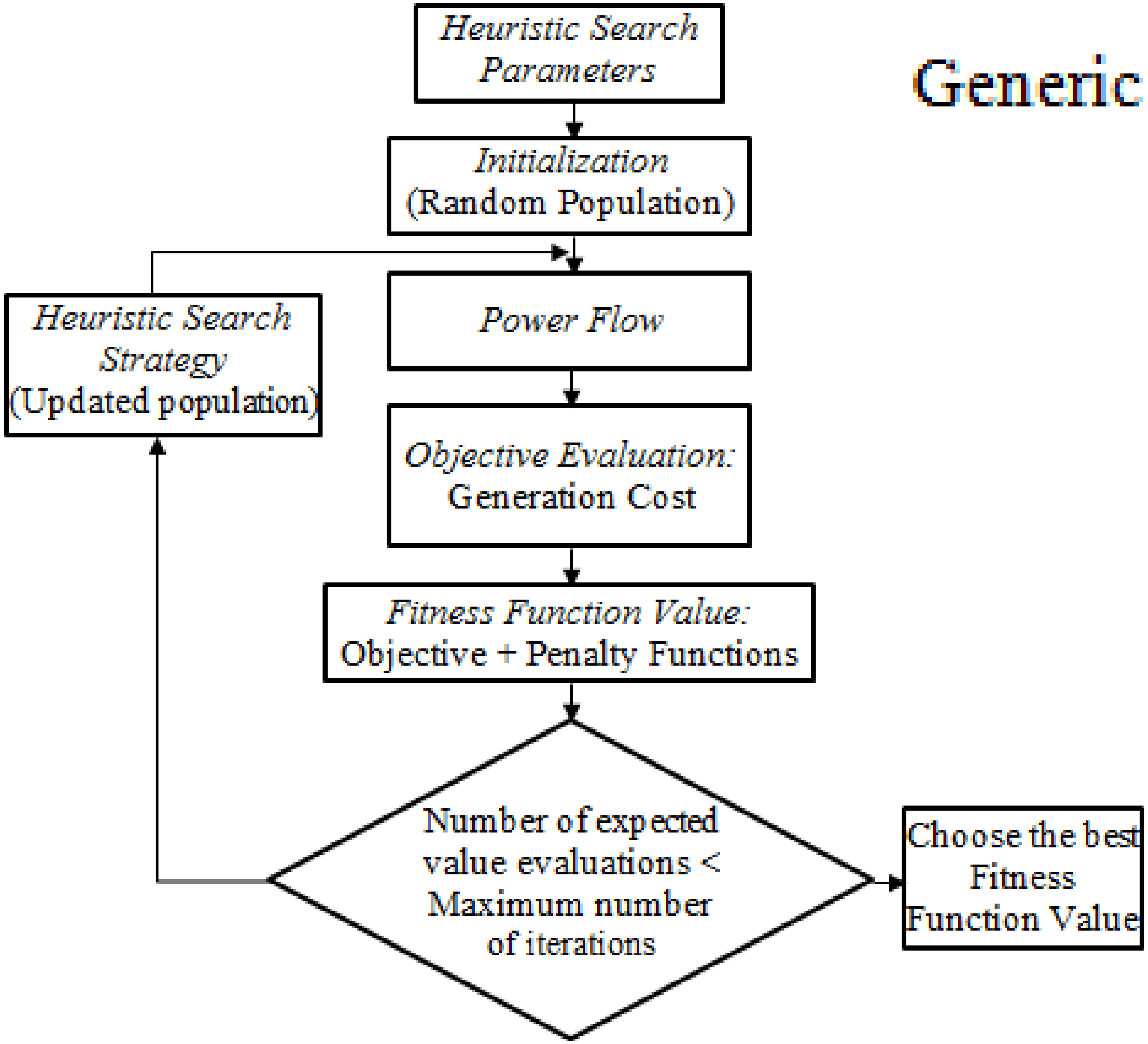
$$s_l \le s_l^{\max}, l \in N_E$$

where N_g is the number of buses with conventional generators, N_{LB} represents the number of load buses, that is to say, buses where P_{di} is different to zero, and N_E represents the number of branches in the network.

Power

2017 competition, test bed 1

Generic flow chart.



2017 competition, test bed 1

Fitness Function Value:
Objective + Penalty Functions

$$PF = \rho \left\{ \begin{array}{l} \sum_{i=1}^{N_g} \left[(Q_{gi} - Q_{gi}^{\min})^2 + (Q_{gi}^{\max} - Q_{gi})^2 \right] + \\ \sum_{i=1}^{N_B} \left[(v_{loadi} - v_{loadi}^{\min})^2 + (v_{loadi}^{\max} - v_{loadi})^2 \right] + \\ \sum_{l=1}^{N_l} (s_l^{\max} - s_l)^2 \end{array} \right\} \quad (39)$$

The penalty function is calculated for non-contingency and contingency (N-1) conditions.

2017 competition, test bed 1

Table 1: Composition of test system

IEEE 57 bus system	
Generators	7
Loads	42
Lines/cables	63
Transformers Stepwise	15
Transformers Fixed tap	2
Shunt compensation Binary On/Off	3

2017 competition, test bed 1

Stochastic OPF for IEEE 57 bus system considering Wind generators

(Cases 1 and 4)

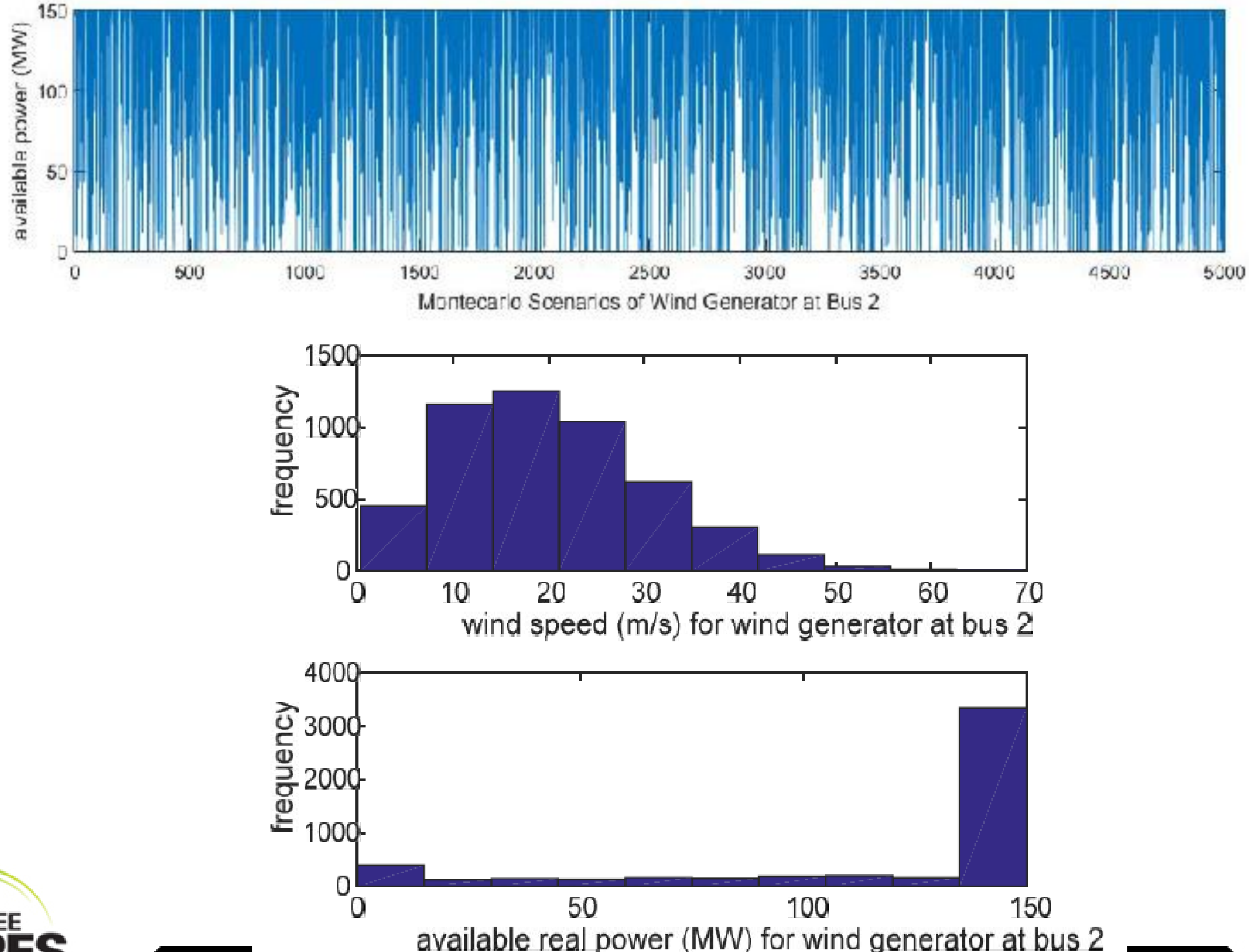
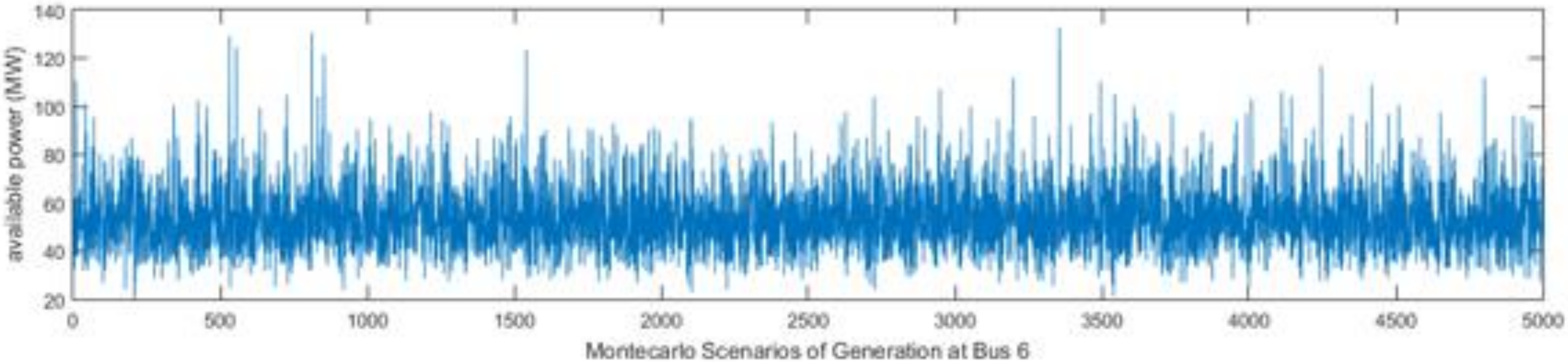


Figure 1. Wind Generator at bus 2.

2017 competition, test bed 1

Stochastic OPF for IEEE 57 bus system considering Wind and Solar



(Cases 2 and 5)

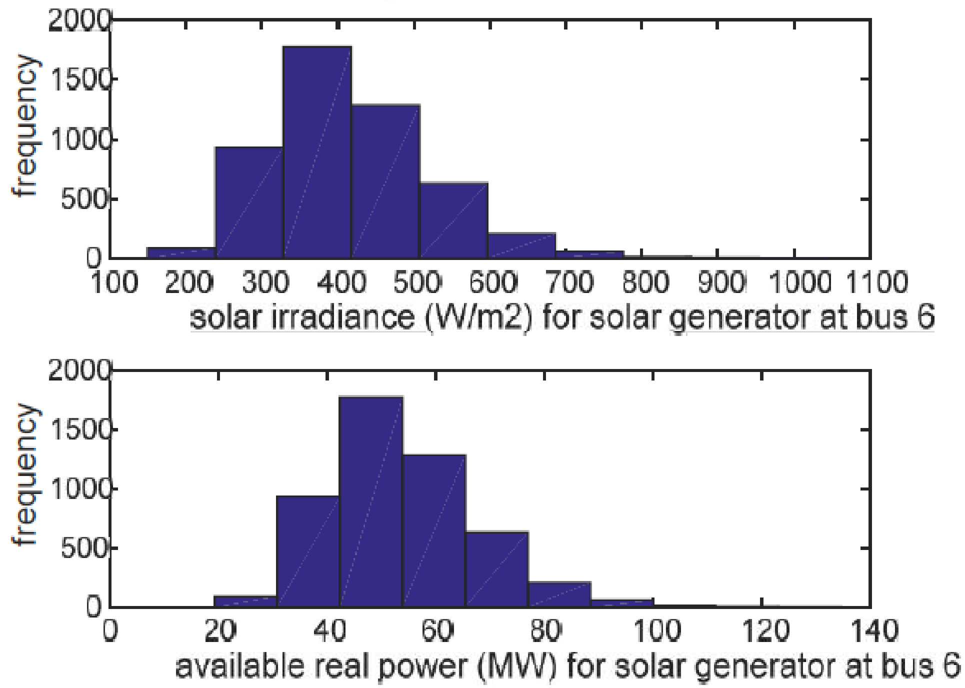
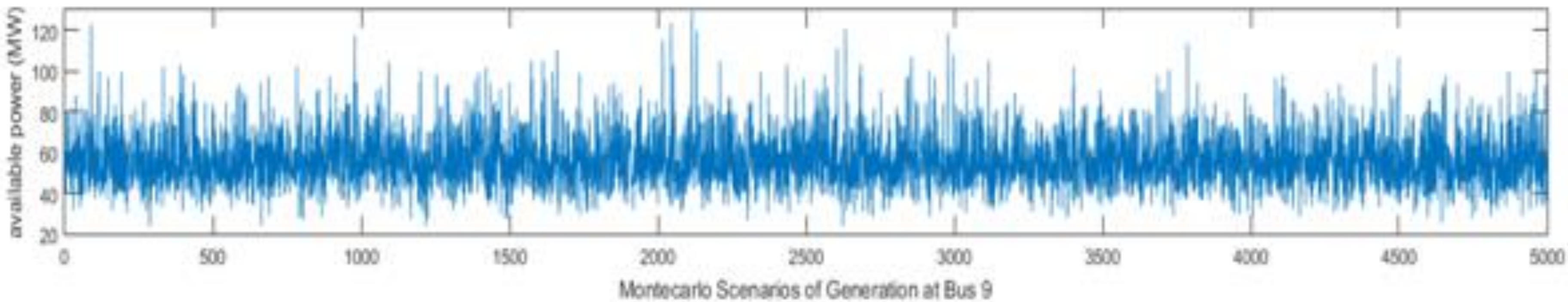
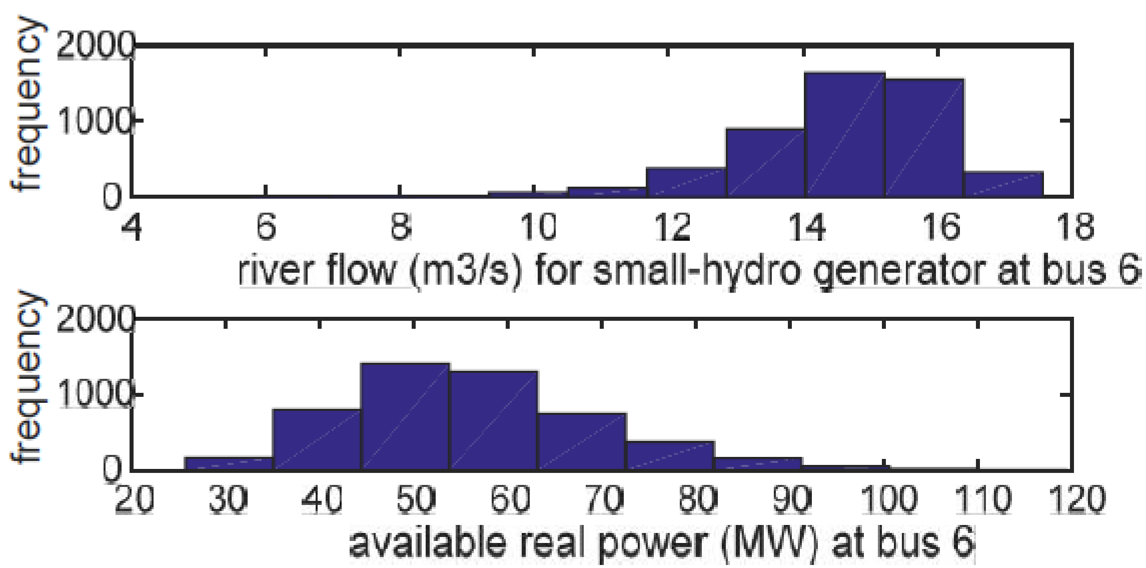


Figure 6. Solar Generator at bus 6.

2017 competition, test bed 1

Stochastic OPF for IEEE 57 bus system considering Wind, Solar and Small-Hydro generators





(Cases 3 and 6)