Main Contents

Introduction]

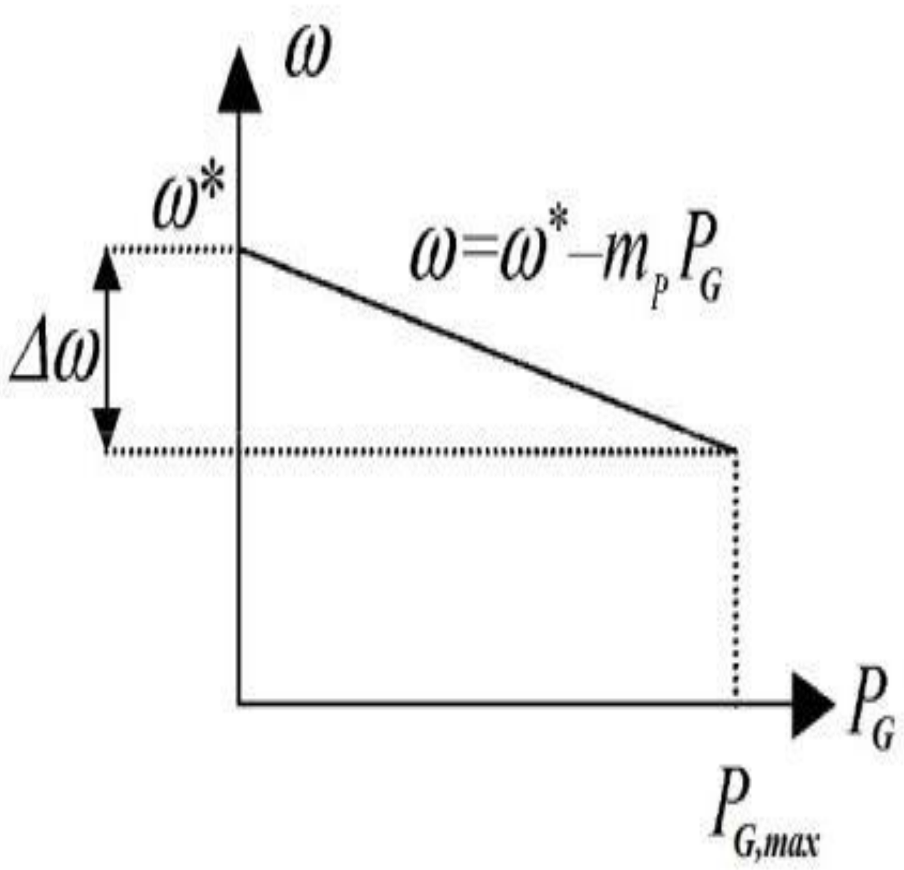
- **Distributed generation source (DG), as a simple type of RER, play a crucial role in keeping the continuity of supply.**
- **DG units such as wind turbine (WT), photovoltaic system (PVS), fuel cell (FC), and energy storage system (ESS) form microgrid.**
- **Therefore, it is necessary controlling frequency, voltage and power sharing can be achieved using droop control on VSI, especially in the isolated operation mode.**
- **With the advent of new optimization algorithms, the trend is to solve many optimizations and engineering problems.**
- **So, the question continues “is there only optimization technique capable of solving all problems?“.**

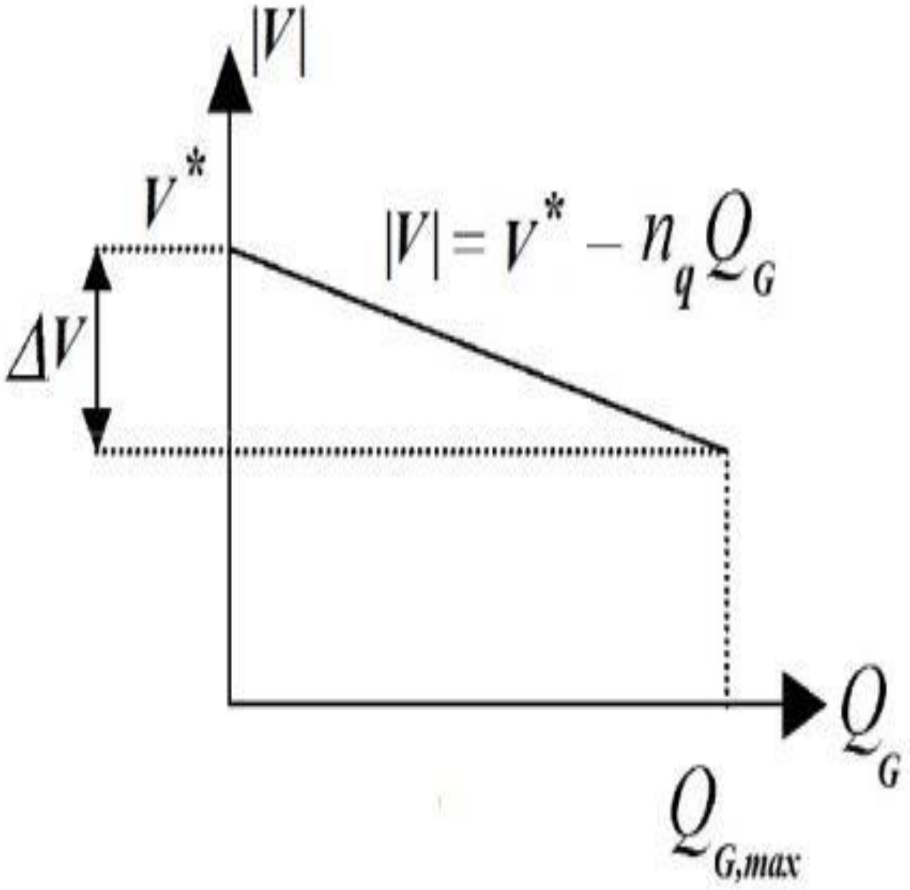
Droop Control

Control Approaches

- Communication-based control (wired methods)
  - Master/slave control techniques
  - Current/power sharing control techniques
- Non-Communication-based control (wireless methods)
  - Sliding-mode voltage control
  - Droop control

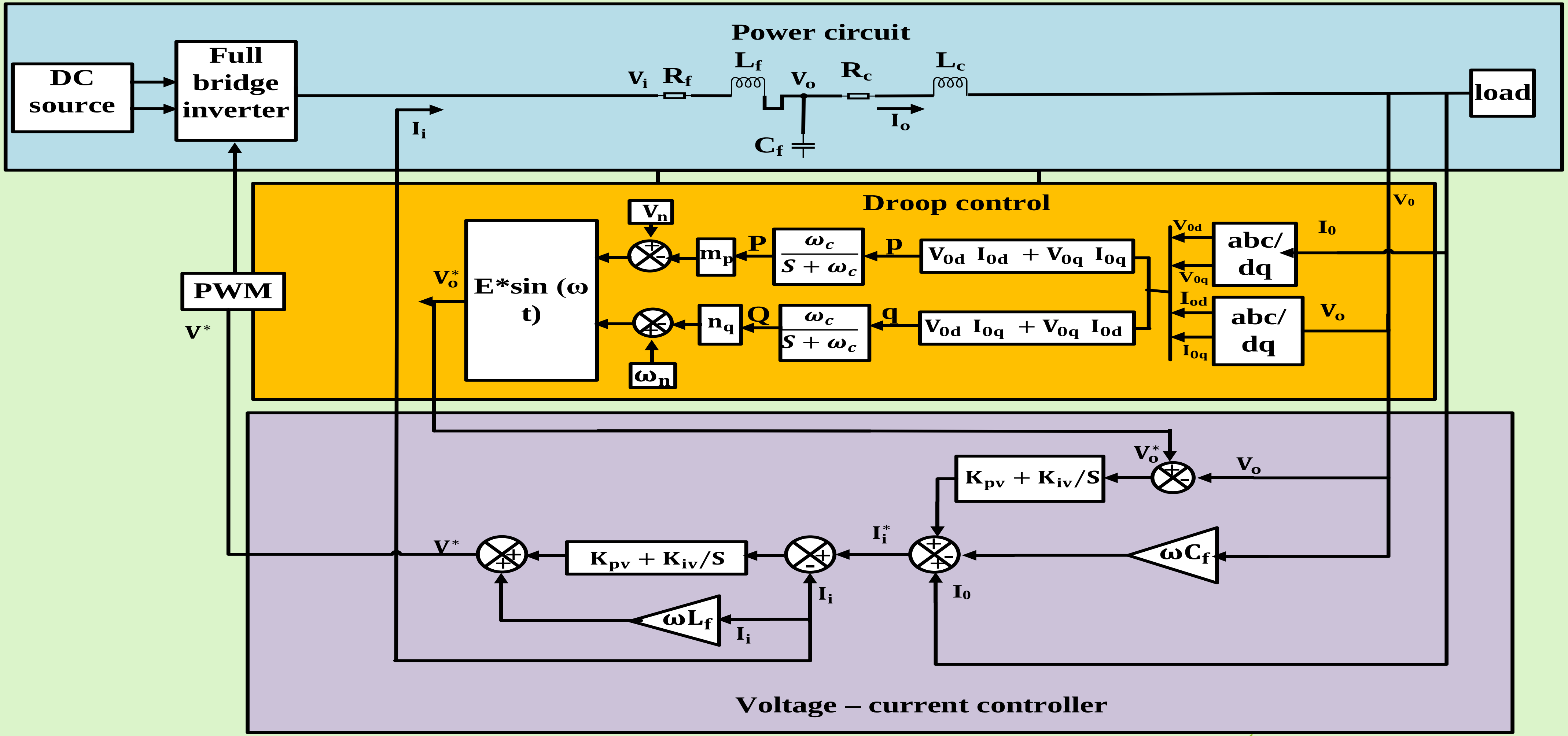
Droop Control





Layers of Control Strategy

1) Power controller 2) Droop control 3) Voltage-current controller



Hybrid Salp Swarm Inspired Algorithm and Particle Swarm Optimization

- The proposed hybrid SSIA-PSO technique is that originated from the hybridizing of SSIA with the updating features of PSO.
- The improvement of SSIA is achieved by applying referential integrity between leaders and followers' candidates via employing both position and velocity update property of PSO.

Particle Swarm Optimization

- The idea of the PSO was inspired by the behaviour of animals such as fish schooling and birds flocking .
- The behaviour of birds for searching of food consists of two parts: -

1) The first part is dispersed .
2) 6the second part is the gather together and going together before they find the right food .o

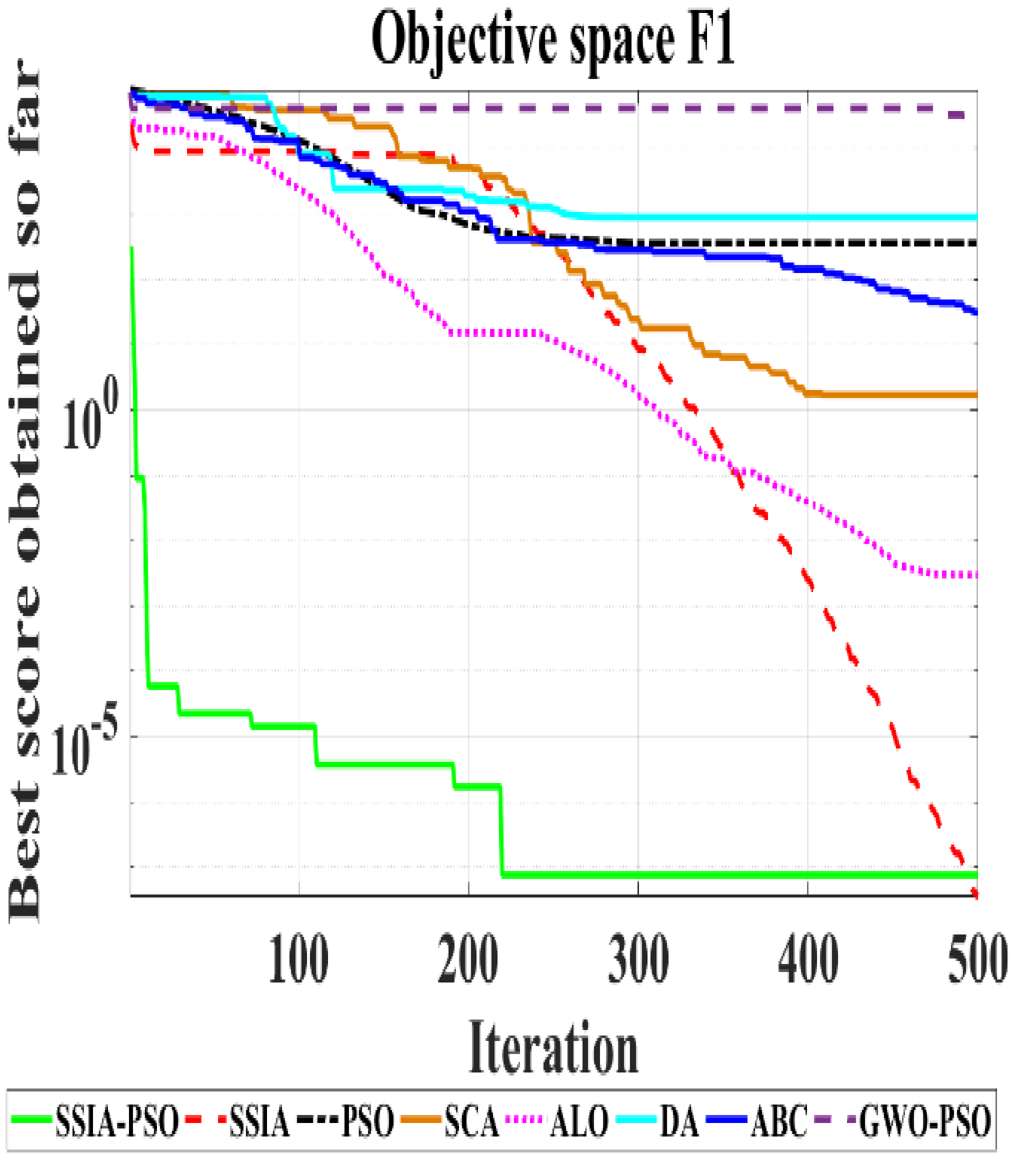
- PSO is optimization technique proposed by Kennedy and Eberhart (1995).

Salp Swarm Inspired Algorithm (SSIA)

- Salp Swarm Algorithm (SSA) is a recently swam intelligence algorithm developed in 2017 by Mirjalili at. El.
- The nature of its form is a transparent barrel-shaped body.
- There are highly like to jellyfishes.
- The Salp living environment is really hard to access, and the salp actually difficult to save them in laboratory environments.
- The Salp chains consist of two groups:- leader and followers.

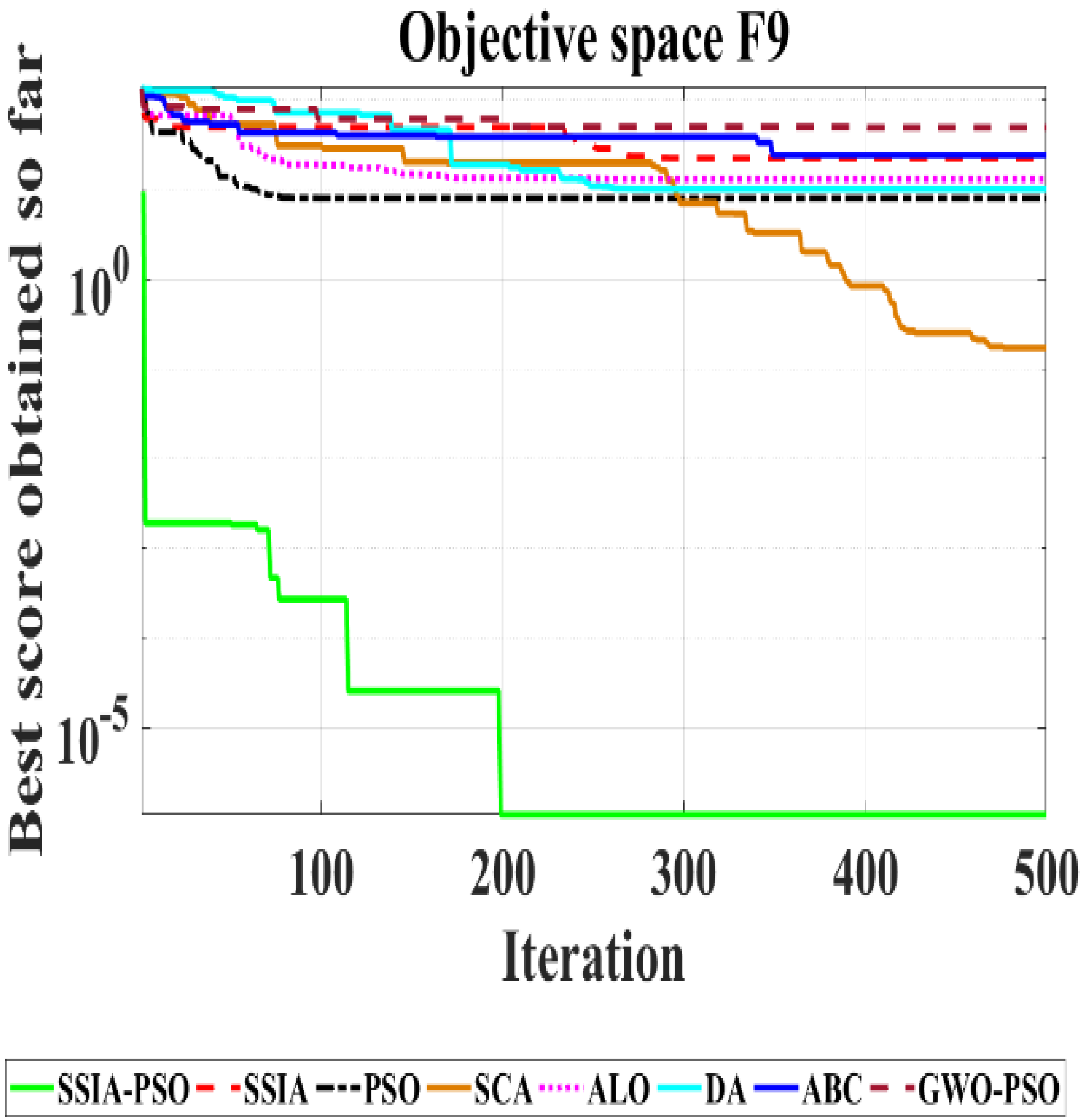
Testing Functions and Result of SSIA-PSO

- The SSIA-PSO algorithm is applied on twenty-three- benchmark functions.
- The benchmark problems are consisting of three groups:-
  1) unimodal
  2) Multimodal
  3) fixed dimension multimodal functions.



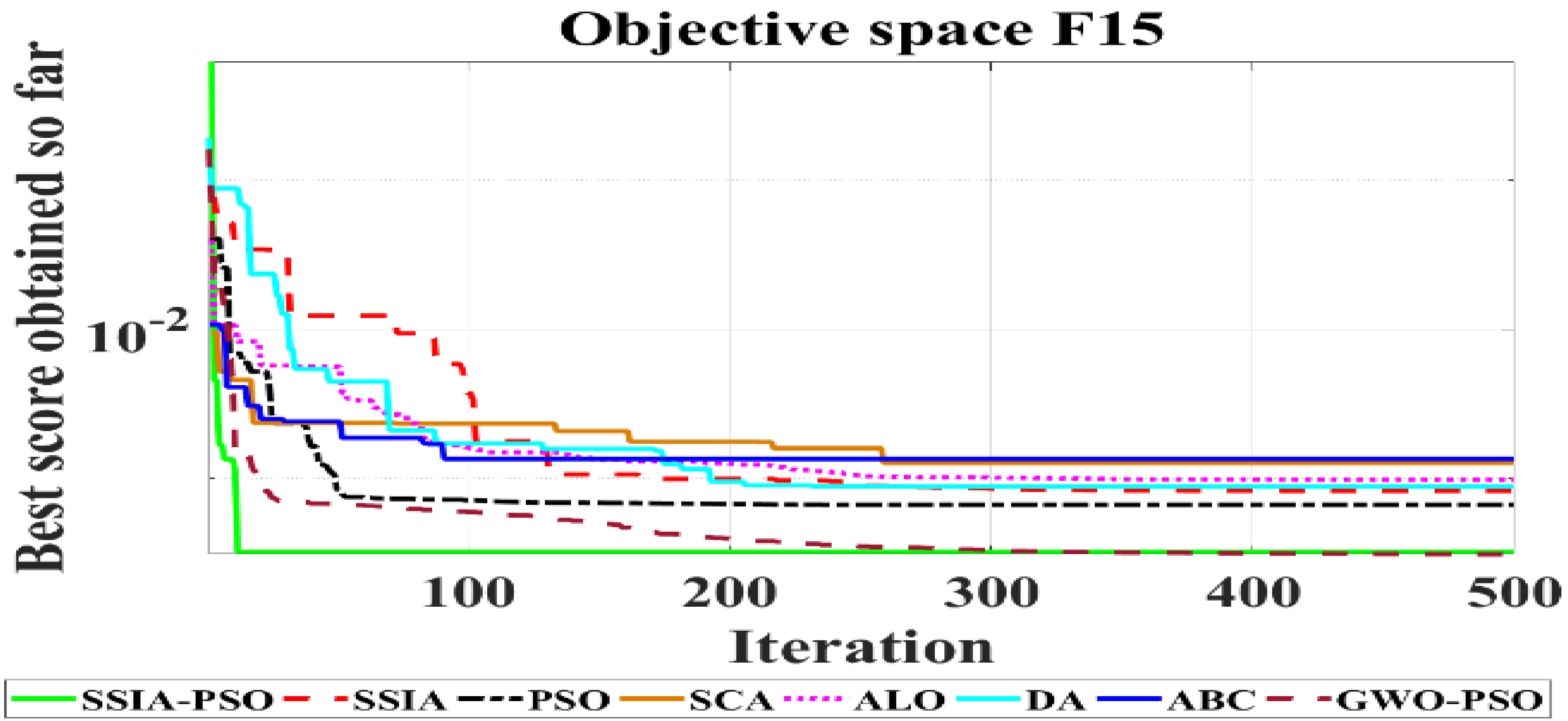
Objective space F1
Best score obtained so far
10^0
10^-5
100
200
300
400
500
Iteration
SSIA-PSO
SSIA
PSO
SCA
ALO
DA
ABC
GWO-PSO

(a)



Objective space F9
Best score obtained so far
10^0
10^-5
100
200
300
400
500
Iteration
SSIA-PSO
SSIA
PSO
SCA
ALO
DA
ABC
GWO-PSO

(b)

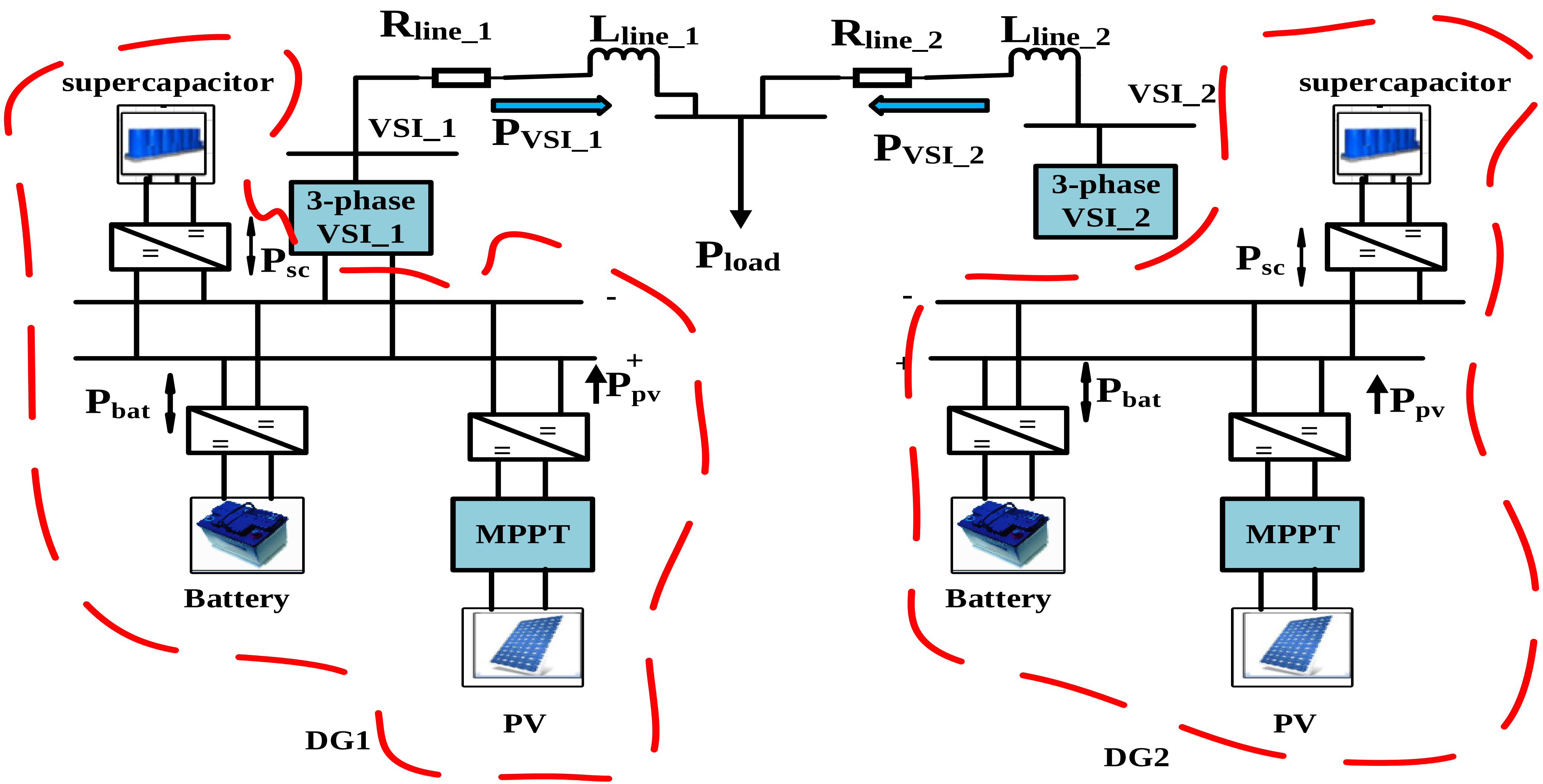


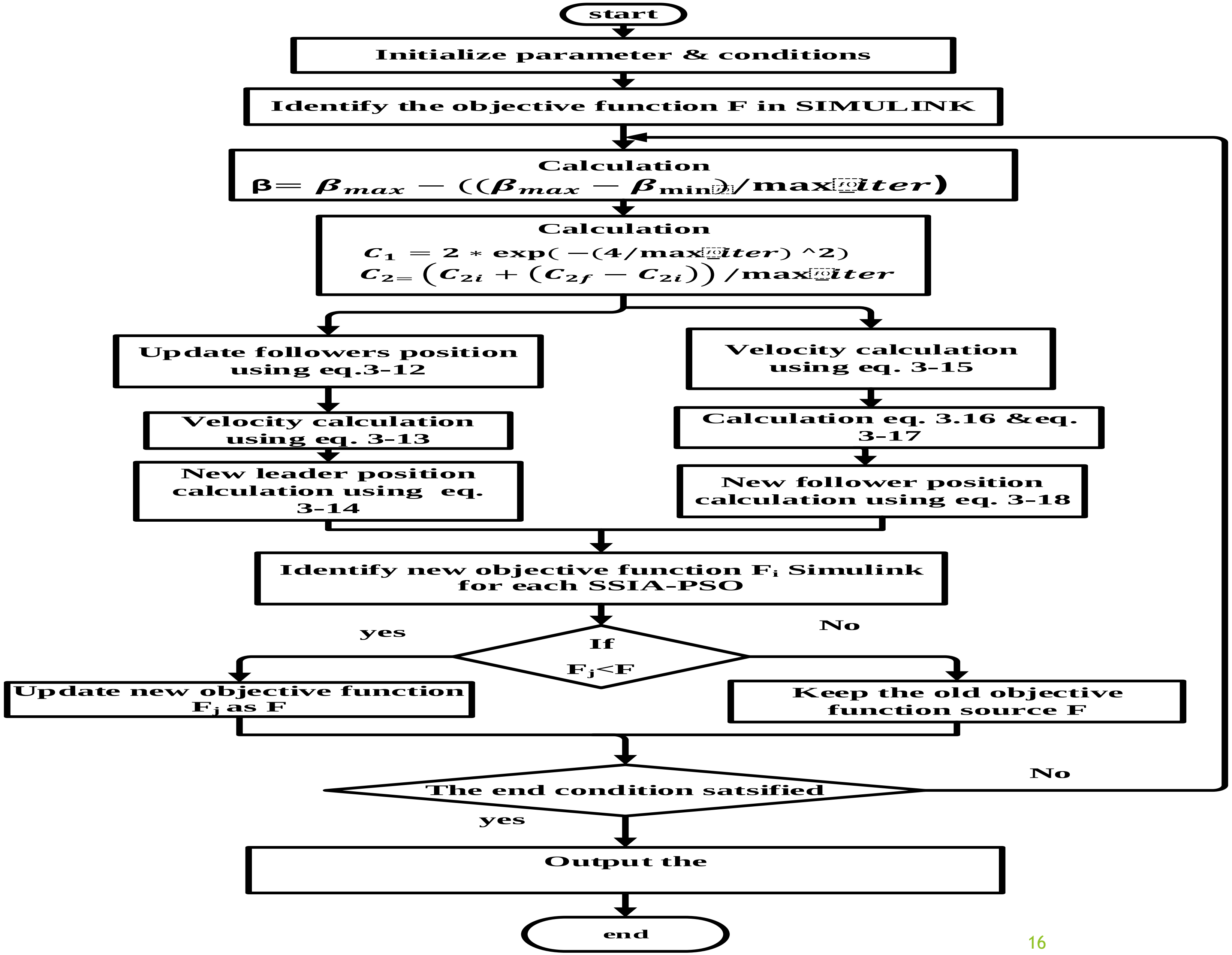
(c)

Convergence characteristics of SSIA-PSO, SSIA, PSO, SCA, ALO, DA, ABC and GWO-PSO: (a) Convergence characteristic to function F1, (b) Convergence characteristic to function F9, (c) Convergence characteristic to function F15

Test Functions		SSIA-PSO	SSIA	PSO	SCA	ALO	DA	ABC	GWO-PSO
F1	Average	3.19 x10^{-23}	1.54 x10^{-07}	1.30 x10^{04}	2.69 x10^{-12}	1.08x10^{-8}	5.22 x10^{0}	2.38 x10^{-05}	1.29 x10^{03}
	Std	7.66 x10^{-23}	1.48 x10^{-07}	2.020 x10^{-04}	7.91 x10^{-12}	9.01x10^{-09}	9.10 x10^{0}	2.26 x10^{-05}	5.12 x10^{03}
F2	Average	7.03 x10^{-12}	4.00 x10^{-04}	2.16 x10^{-01}	9.26 x10^{-10}	1.76 x10^{0}	1.66 x10^{0}	6.26 x10^{-06}	9.76 x10^{04}
	Std	2.62 x10^{-11}	2.00 x10^{-03}	4.490 x10^{-01}	2.51 x10^{-09}	6.99 x10^{0}	1.14 x10^{0}	5.22 x10^{-06}	4.90 x10^{05}
F3	Average	1.15 x10^{-20}	5.38 x10^{-07}	2.140 x10^{03}	5.49 x10^{-01}	3.21 x10^{-02}	1.72 x10^{02}	2.15 x10^{02}	9.88 x10^{03}
	Std	4.84 x10^{-20}	1.11 x10^{-06}	3.130 x10^{03}	3.00 x10^{0}	7.42 x10^{-02}	1.72 x10^{02}	1.02 x10^{02}	1.91 x10^{04}
F4	Average	1.32 x10^{-12}	2.86 x10^{-05}	1.25 x10^{01}	1.05 x10^{-03}	2.68 x10^{-02}	3.49 x10^{0}	3.72 x10^{0}	1.66 x10^{01}
	Std	2.02 x10^{-12}	4.39 x10^{-05}	1.72 x10^{01}	2.58 x10^{-03}	9.64x 10^{-02}	3.05x10^{0}	7.79 x 10^{-01}	2.26 x10^{01}
F5	Average	8.88 x10^{0}	1.54 x10^{02}	2.52 x10^{02}	7.36 x10^{0}	1.84 x10^{02}	2.21 x10^{03}	2.01 x10^{01}	7.14 x10^{06}
	Std	1.40 x10^{-02}	3.13 x10^{02}	5.39 x10^{02}	3.81 x10^{-01}	4.11 x10^{02}	6.06 x10^{03}	2.1.8 x10^{01}	2.52 x10^{07}
F6	Average	6.97 x10^{-01}	1.02 x10^{-09}	9.27 x10^{02}	4.52 x10^{-01}	8.58 x10^{-09}	6.78 x10^{0}	3.06 x10^{-05}	2.56 x10^{03}
	Std	1.99 x10^{-01}	3.69 x10^{-10}	2.94 x10^{03}	1.55 x10^{-01}	4.17 x10^{-09}	1.05 x10^{01}	3.54 x10^{-05}	7.56 x10^{03}
F7	Average	1.32 x10^{-04}	1.50 x10^{-02}	1.30 x10^{-02}	2.53 x10^{-03}	2.60 x10^{-02}	3.35 x10^{-02}	1.38 x10^{-02}	2.34 x10^{0}
	Std	1.00 x10^{-04}	9.00 x10^{-03}	1.60 x10^{-02}	1.97 x10^{-03}	1.29 x10^{-02}	2.19 x10^{-02}	5.2 x10^{-03}	6.77 x10^{0}
F8	Average	-2.66 x10^{03}	-2.72 x10^{03}	-1.48 x10^{03}	-2.11 x10^{03}	-2.36 x10^{03}	-2.76 x10^{03}	-2.75 x10^{03}	-7.38 x10^{03}
	Std	4.03 x10^{02}	2.70 x10^{02}	2.69 x10^{02}	1.98 x10^{02}	5.87 x10^{02}	3.07 x10^{02}	3.00x10^{02}	9.19 x10^{02}
F9	Average	0	1.75 x10^{01}	1.12 x10^{01}	2.17 x10^{0}	2.15 x10^{01}	2.94 x10^{01}	2.89 x10^{01}	7.18 x10^{01}
	Std	0	7.44 x10^{0}	7.04 x10^{0}	5.81 x10^{0}	9.78 x10^{0}	1.09 x10^{01}	5.51 x10^{0}	6.67 x10^{01}
F10	Average	1.23 x10^{-12}	6.39 x10^{-01}	3.12 x10^{0}	1.92 x10^{-07}	1.93 x10^{-01}	2.80 x10^{0}	3.36 x10^{-02}	4.58 x10^{0}
	Std	2.05 x10^{-12}	9.88 x10^{-01}	2.22 x10^{0}	3.33 x10^{-07}	4.38 x10^{-01}	1.03 x10^{0}	2.20 x10^{-02}	5.65 x10^{0}
F11	Average	0	2.60 x10^{-01}	6.29 x10^{01}	1.41 x10^{-01}	2.27 x10^{-01}	5.43 x10^{-01}	4.18x10^{-01}	4.63 x10^{01}
	Std	0	2.05 x10^{-02}	4.90 x10^{01}	2.38 x10^{-01}	7.27 x10^{-02}	2.85 x10^{-01}	1.08x10^{-01}	9.57 x10^{01}
F12	Average	1.36 x10^{-01}	7.53 x10^{-01}	5.72 x10^{05}	8.97 x10^{-02}	3.13 x10^{0}	2.05 x10^{0}	3.25 x10^{-03}	1.08 x10^{07}
	Std	5.60 x10^{-02}	1.11 x10^{0}	2.18 x10^{06}	3.47 x10^{-02}	3.35 x10^{0}	2.05 x10^{0}	1.29 x10^{-02}	3.59 x10^{07}
F13	Average	5.78 x10^{-03}	1.10 x10^{-03}	3.39 x10^{06}	3.36 x10^{-01}	1.43 x10^{-03}	9.92 x10^{-01}	8.91 x10^{-03}	1.29 x10^{07}
	Std	3.60 x10^{-03}	3.30 x10^{-03}	1.86 x10^{07}	9.49 x10^{-02}	4.63 x10^{-03}	8.44 x10^{-01}	5.36 x10^{-03}	5.35 x10^{07}
F14	Average	1.79 x10^{0}	1.13 x10^{0}	2.99 x10^{0}	1.86 x10^{0}	2.81 x10^{0}	1.43 x10^{0}	9.98 x10^{-01}	4.09 x10^{0}
	Std	1.06 x10^{0}	3.43 x10^{-01}	4.39 x10^{0}	9.99 x10^{-01}	2.04 x10^{0}	8.89 x10^{-01}	3.03 x10^{-03}	4.16 x10^{0}
F15	Average	3.37 x10^{-04}	1.50 x10^{-03}	2.00 x10^{-03}	1.11 x10^{-03}	2.17 x10^{-03}	3.43 x10^{-03}	1.16 x10^{-03}	6.79 x10^{-03}
	Std	1.94 x10^{-05}	4.00 x10^{-03}	3.70 x10^{-03}	3.35 x10^{-04}	4.95 x10^{-03}	5.88 x10^{-03}	1.23 x10^{-04}	8.81 x10^{-03}
F16	Average	-1.02 x10^{0}	-1.03 x10^{0}	-1.03 x10^{0}	-1.03 x10^{0}	-1.032x10^{0}	-1.03 x10^{0}	-1.031 x10^{0}	-1.032x10^{0}
	Std	4.50 x10^{-03}	2.33 x10^{-14}	7.61 x10^{-07}	4.46 x10^{-05}	9.41 x10^{-14}	6.46 x10^{-07}	9.27 x10^{-08}	1.21 x10^{-04}
F17	Average	3.98 x10^{-01}	3.97 x10^{-01}	3.98 x10^{-01}	3.99 x10^{-1}	3.979 x10^{-1}	3.98 x10^{-01}	3.979 x10^{-01}	3.98x10^{-01}
	Std	3.70 x10^{-04}	5.31 x10^{-14}	2.28 x10^{-04}	1.93 x10^{-03}	1.58 x10^{-13}	5.74 x10^{-07}	2.82 x10^{-05}	2.91x10^{0-06}
F18	Average	3.29 x10^{0}	3.00 x10^{0}	3.00 x10^{0}	3.00 x10^{0}	3.00 x10^{0}	3.00 x10^{0}	3 x10^{0}	3.00x10^{0}
	Std	3.72 x10^{-01}	3.18 x10^{-13}	5.21 x10^{-05}	1.16 x10^{-04}	5.69 x10^{-13}	4.65 x10^{-06}	4.95 x10^{-06}	2.97 x10^{-03}
F19	Average	-3.85 x10^{0}	-3.86 x10^{0}	-3.86 x10^{0}	-3.85 x10^{0}	-3.87 x10^{0}	-3.86 x10^{0}	-3.86 x10^{0}	-3.86 x10^{0}
	Std	1.10 x10^{-02}	1.32 x10^{-10}	3.10 x10^{-03}	3.33 x10^{-03}	2.14 x10^{-13}	4.70 x10^{-04}	4.05 x10^{-10}	3.64 x10^{-03}
F20	Average	-3.20 x10^{0}	-3.23 x10^{0}	-3.28 x10^{0}	-2.83 x10^{0}	-3.29 x10^{0}	-3.24 x10^{0}	-3.32 x10^{0}	-3.14x10^{0}
	Std	7.40 x10^{-02}	6.20 x10^{-02}	6.40 x10^{-02}	3.84 x10^{-01}	5.56 x10^{-02}	8.34 x10^{-02}	4.28 x10^{-06}	2.43 x10^{-01}
F21	Average	-5.02 x10^{0}	-3.23 x10^{0}	-5.63 x10^{0}	-2.38 x10^{0}	-5.54 x10^{0}	-7.37 x10^{0}	-9.92 x10^{0}	-6.96 x10^{0}
	Std	1.10 x10^{-02}	2.98 x10^{0}	3.18 x10^{0}	1.86 x10^{0}	2.79 x10^{0}	2.91 x10^{0}	7.63 x10^{-01}	3.55 x10^{0}
F22	Average	-5.05 x10^{0}	-8.85 x10^{0}	-5.51 x10^{0}	-3.49 x10^{0}	-7.03 x10^{0}	-7.05 x10^{0}	-1.04 x10^{01}	-7.78x10^{0}
	Std	1.50 x10^{-02}	2.91 x10^{0}	3.61 x10^{0}	2.08 x10^{0}	3.33 x10^{0}	2.80 x10^{0}	1.12 x10^{-07}	3.35x10^{0}
F23	Average	-5.26 x10^{0}	-8.66 x10^{0}	-6.71 x10^{0}	-4.27 x10^{0}	-6.28 x10^{0}	-8.14 x10^{0}	-1.05 x10^{01}	-8.07 x10^{0}
	Std	9.164 x10^{-01}	3.23 x10^{0}	3.70 x10^{0}	2.29 x10^{0}	3.42 x10^{0}	3.25 x10^{0}	2.33 x10^{0}	3.49 x10^{0}

SSIA-PSO application in microgrid





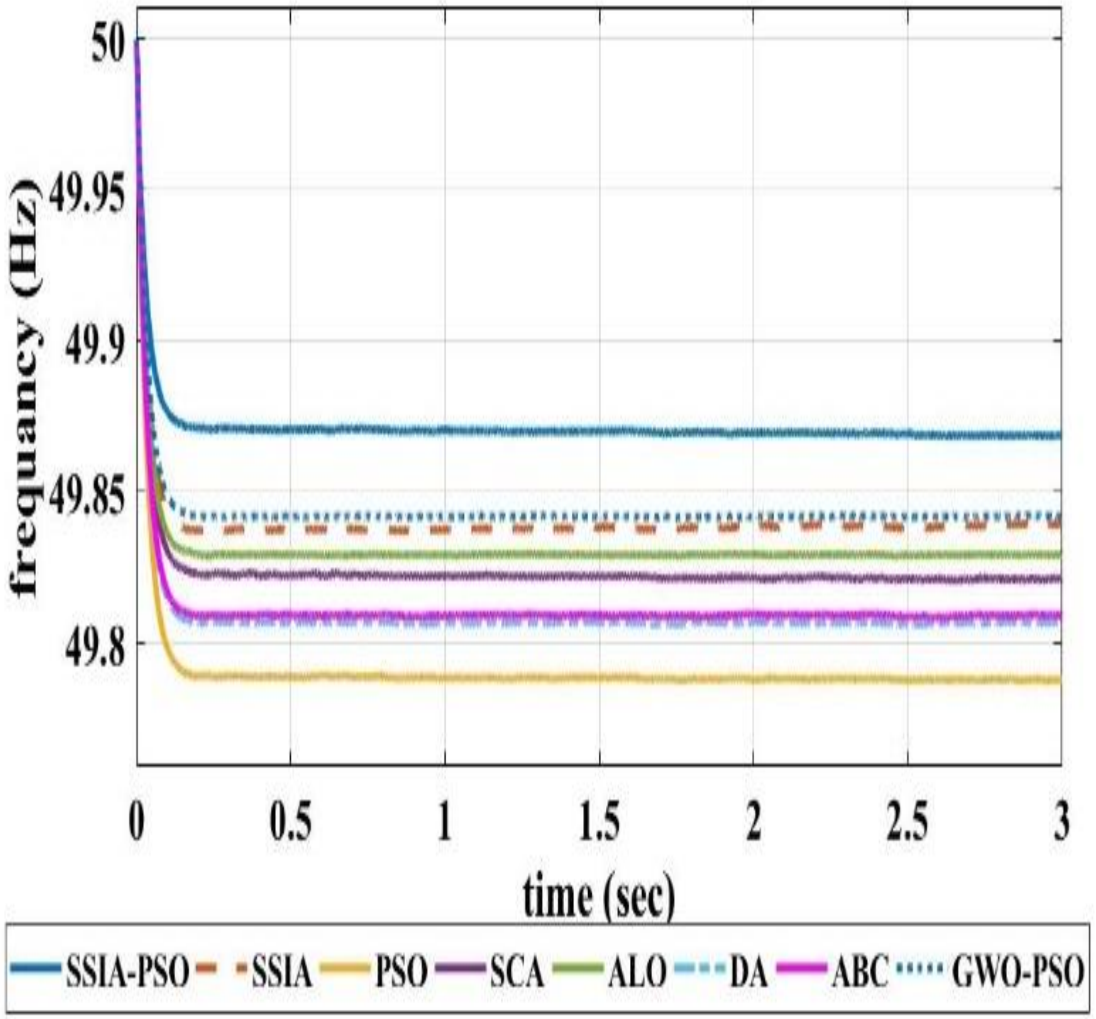
Hybrid Salp Swarm Inspired Algorithm and Particle Swarm Optimization

Gains of PI and droop control coefficients

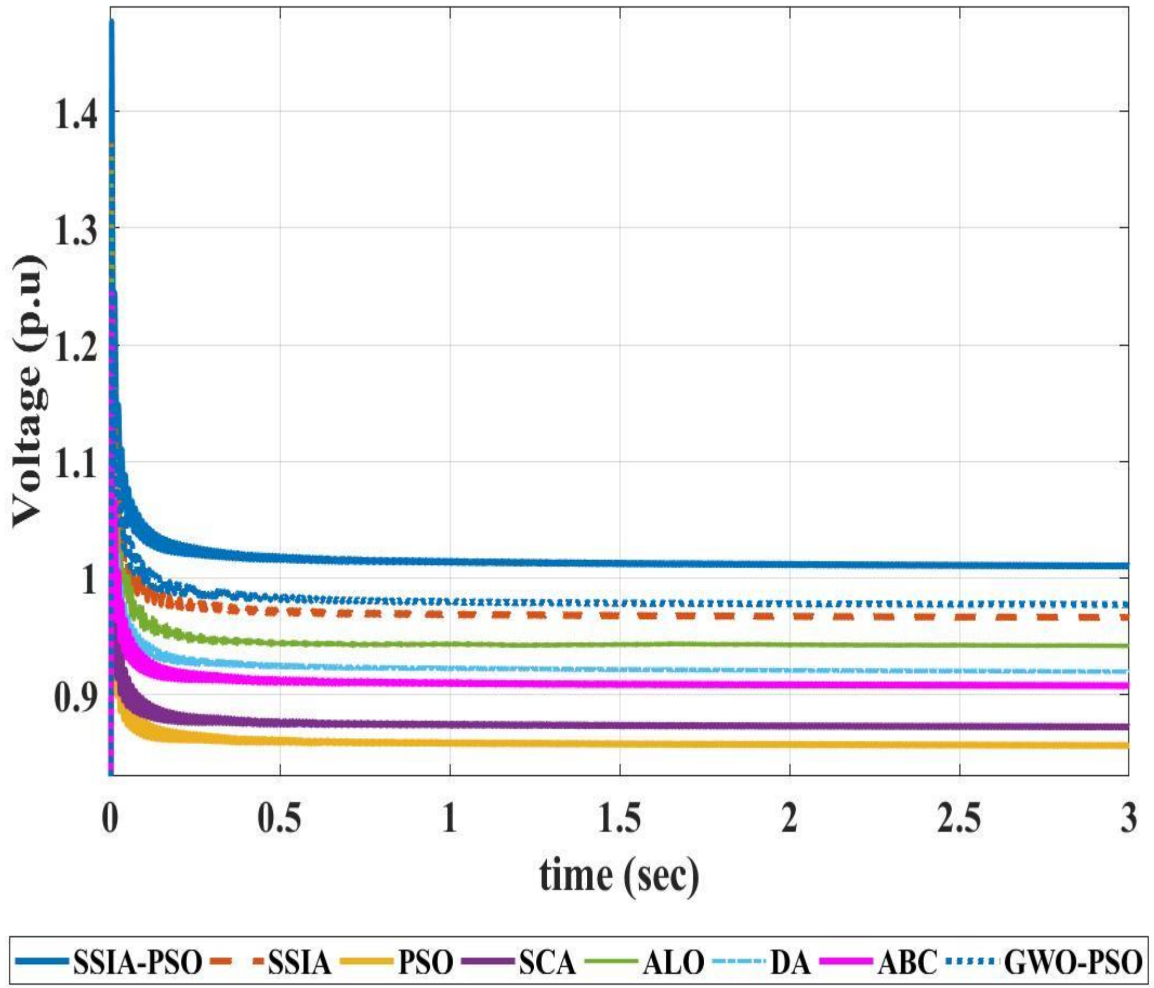
	IAE	ISE	ITAE	ITSE
Objective function	1.02×10^{7}	4.86×10^{8}	6.08×10^{6}	3.52×10^{8}
K_{p1}	0.729378	0.297968	0.312331	0.435606
K_{i1}	375.0570	584.8307	353.2782	492.2117
K_{p2}	0.608674	0.698931	0.550147	0.265350
K_{i2}	263.1959	559.3624	351.9411	284.2597
K_{p3}	8.185111	14.82072	15.30740	12.32775
K_{i3}	7580.512	14793.52	12837.96	10874.02
K_{p4}	12.03902	11.76199	8.163614	11.41256
K_{i4}	5232.952	8675.729	10772.97	14010.86
n_q	0.239131	0.374225	0.347973	0.345697
m_p	0.019751	0.013487	0.013713	0.020106
Time Taken (min)	199.8119	203.2725	205.7367	203.4736

Results of the Applied eight Optimization Techniques

	SSIA	PSO	SCA	ALO	DA	ABC	GWO-PSO	SSIA-PSO
Objective function	10.25 x10^6	12.66 x10^6	13.76 x10^6	11.22 x10^6	11.25 x10^6	18.46 x10^6	9.35 x10^6	6.08 x10^6
K_{p1}	0.691433	0.557908	0.622222	0.532215	0.253903	0.641502	0.688742	0.312331
K_{i1}	311.4964	475.0824	242.9766	521.9489	382.4229	530.0400	537.406	353.2782
K_{p2}	0.548548	0.513765	0.288695	0.537495	0.386742	0.470766	0.381130	0.550147
K_{i2}	543.6527	565.1678	550.6742	537.8442	438.6973	349.2290	449.9315	351.9411
K_{p3}	11.27808	13.09909	7.515493	14.58615	9.276742	12.22560	15.16175	15.30740
K_{i3}	13879.68	12410.52	14587.14	6500.108	14416.69	6358.140	12187.15	12837.96
K_{p4}	10.25541	13.05646	6.854758	7.378885	8.530060	9.003440	14.31799	8.163614
K_{i4}	14414.39	11132.63	13968.29	10557.64	6300.102	13267.80	5846.391	10772.97
n_q	0.272247	0.225909	0.228627	0.367958	0.390588	0.266158	0.203386	0.347973
m_p	0.014868	0.009724	0.012441	0.014005	0.015810	0.015636	0.013584	0.013713
Time Taken (min)	207.2686	219.1358	218.7167	212.2842	209.5110	224.4803	207.5955	205.7367



Frequency response of MG equipped with droop controller tuned via seven optimization techniques

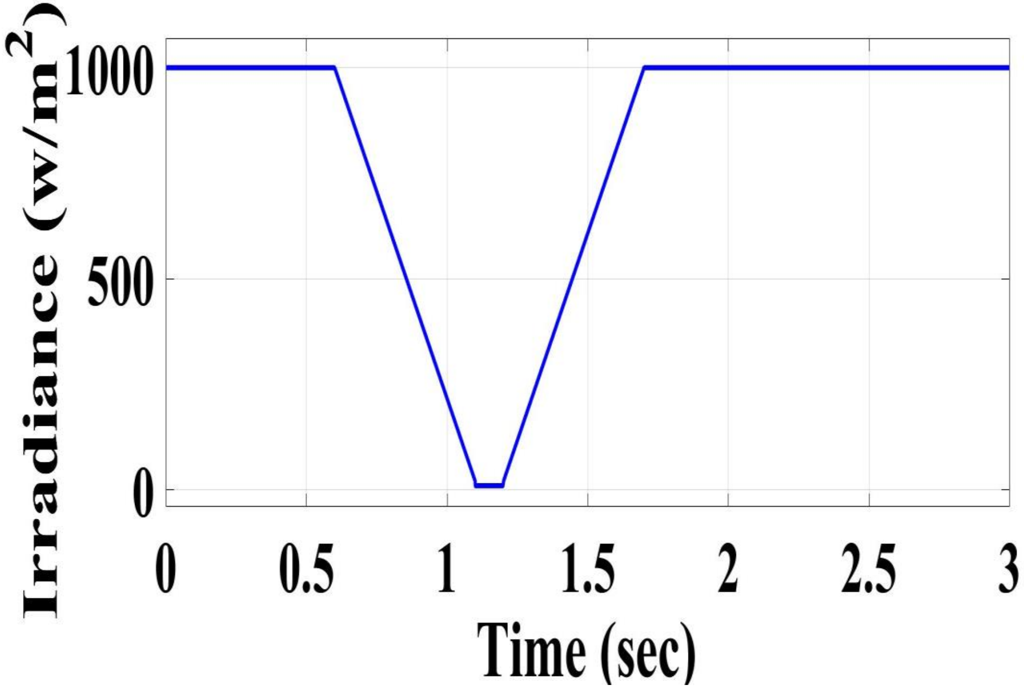


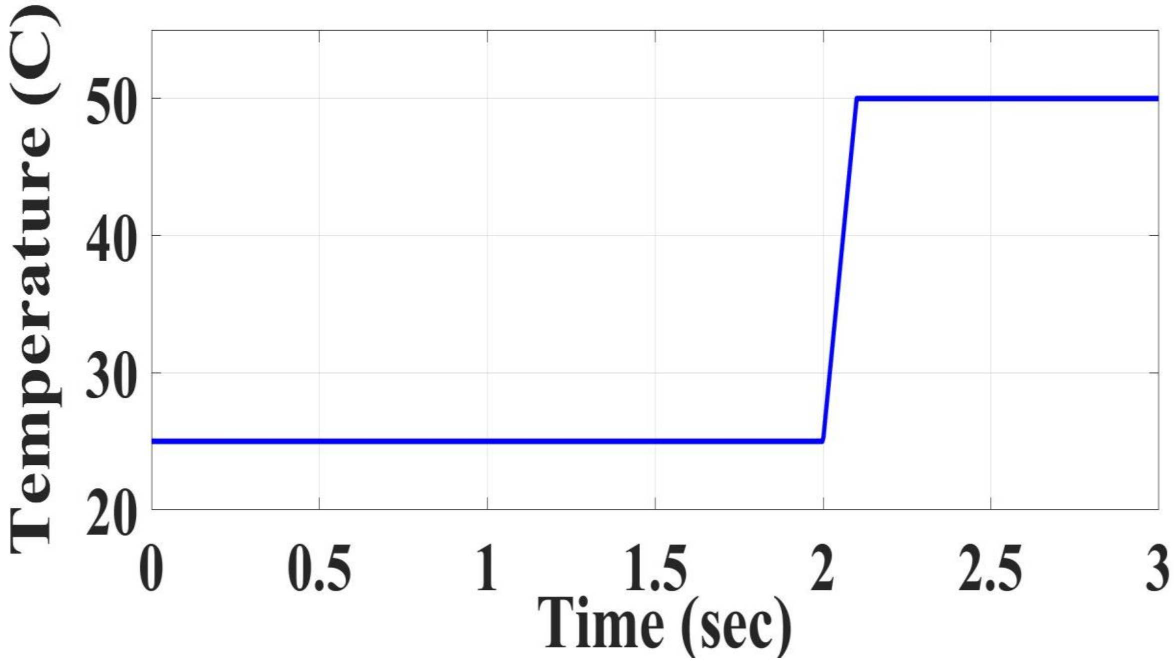
Voltage response of MG equipped with droop controller tuned via seven optimization techniques

Simulation Results

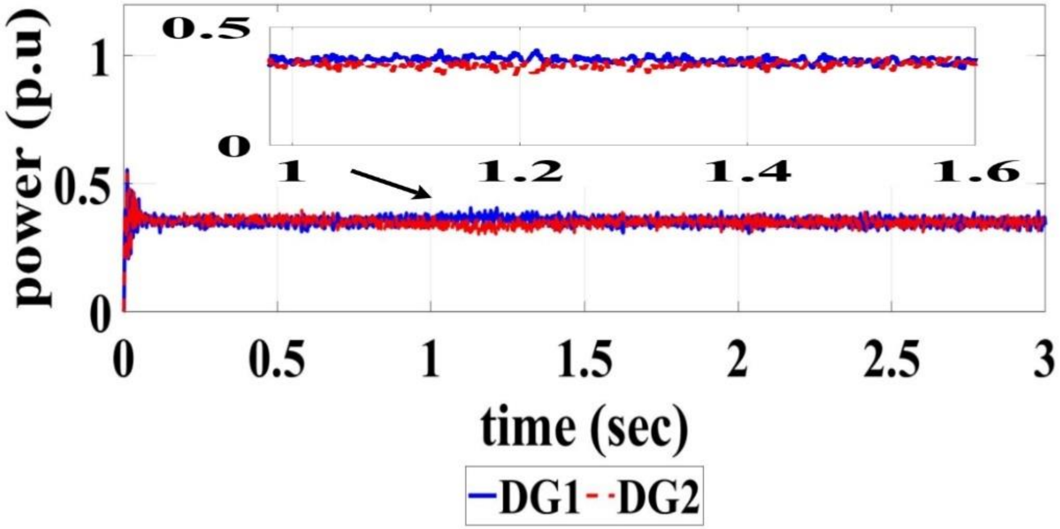
There are eight scenarios depending on load effect and RERs variability, such as (variable irradiance and temperature):-

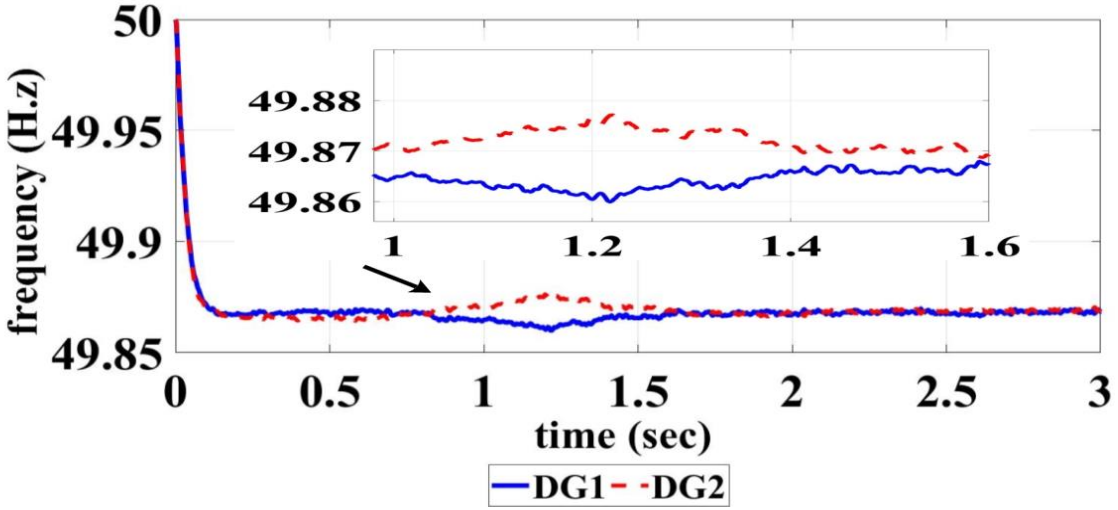
1) Islanding Mode with Fixed Cyclic Load Variations Scenario (IMFCLVS)
2) Islanding Mode with Unit Step Cyclic Load Variations Scenario (IMUSCLVS)
3) Islanding Mode with Continuous Cyclic Load Variations Scenario (IMCCLVS)
4) Islanding Mode with Ramp Load Variations Scenario (IMRLVS)
5) Islanding Mode with Unit Step Cyclic Load Variations, by Increase of Gains of PI Controllers and Droop Control Coefficients +20%
6) Islanding Mode with Unit Step Cyclic Load Variations, by Decrease of Gains of PI Controllers and Droop Control Coefficients -20%
7) Islanding Mode with Unit Step Cyclic Load Variations, by Increase of Line Parameters +20%.
8) Islanding Mode with Unit Step Cyclic Load Variations, by Decrease of Line Parameters -20%.

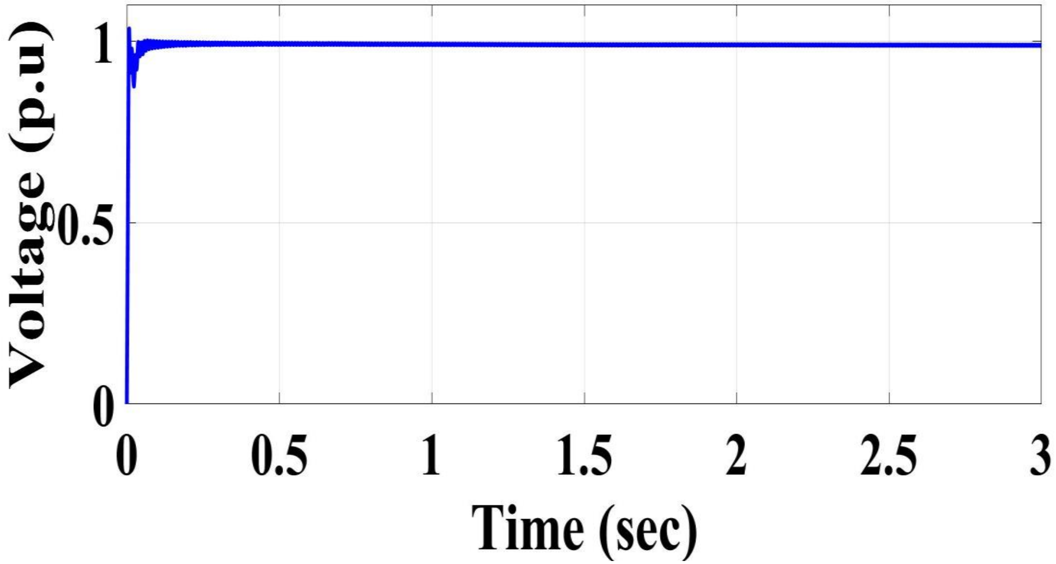

Irradiance (w/m2)
1000
500
0
0
0.5
1
1.5
2
2.5
3
Time (sec)

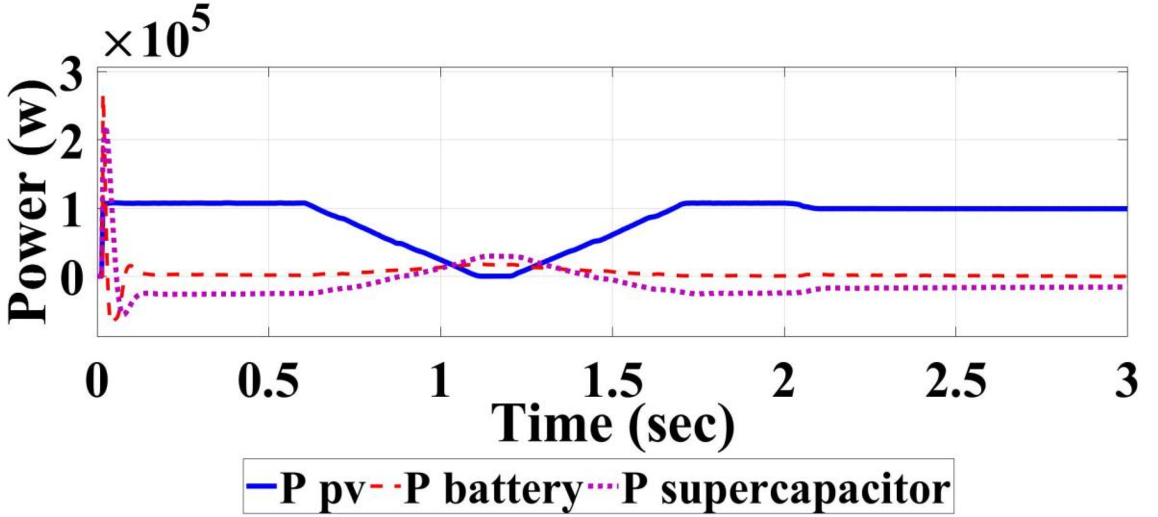

Temperature (C)
50
40
30
20
0
0.5
1
1.5
2
2.5
3
Time (sec)

1) Islanding Mode with Fixed Cyclic Load Variations Scenario (IMFCLVS)

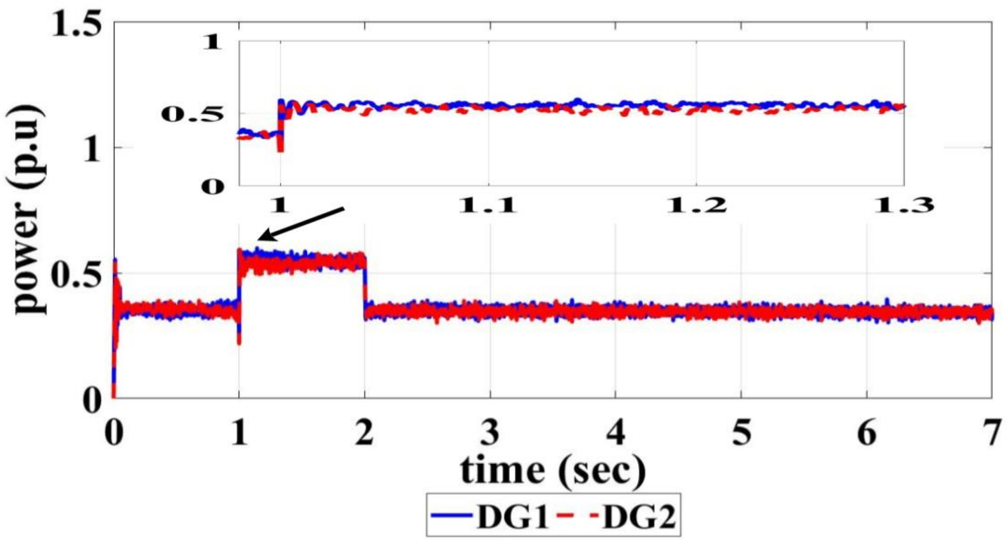


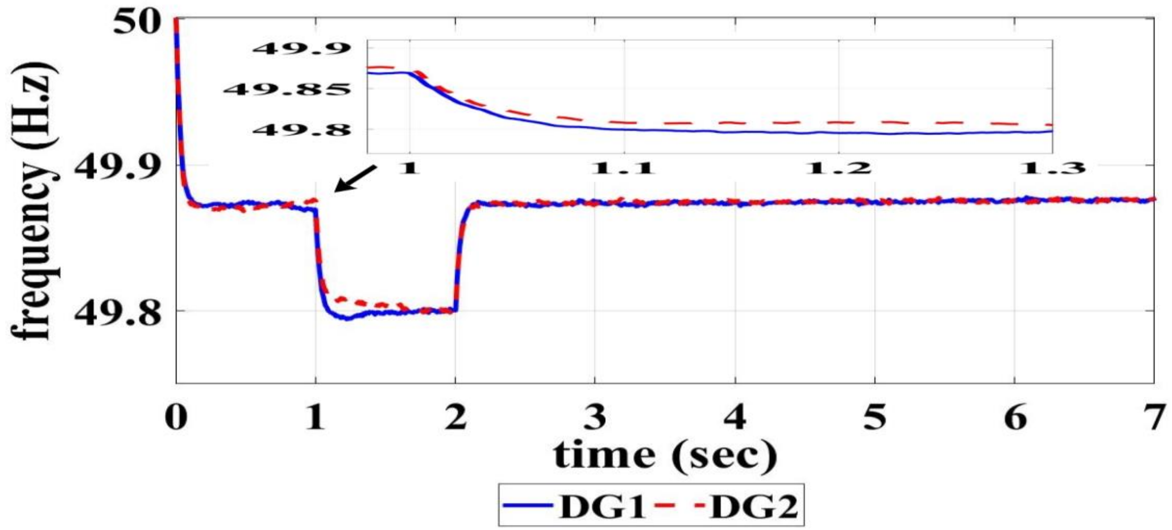


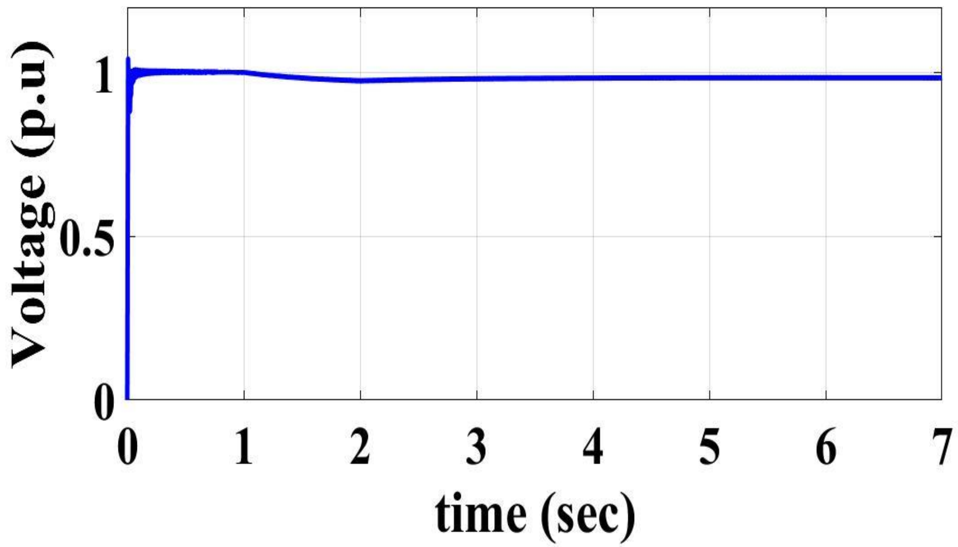


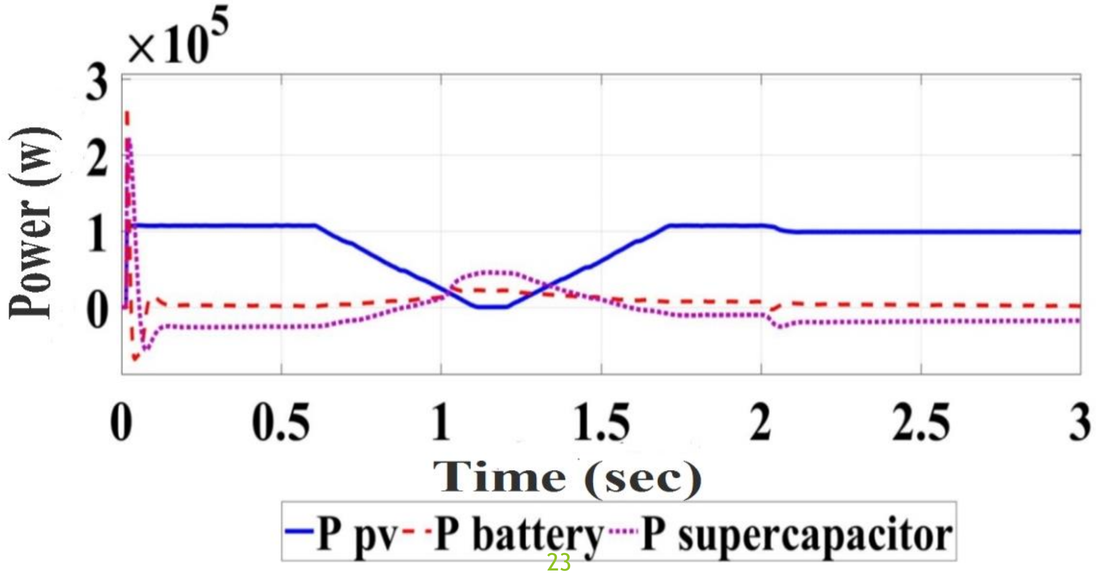


2) Islanding Mode with Unit Step Cyclic Load Variations Scenario (IMUSCLVS)

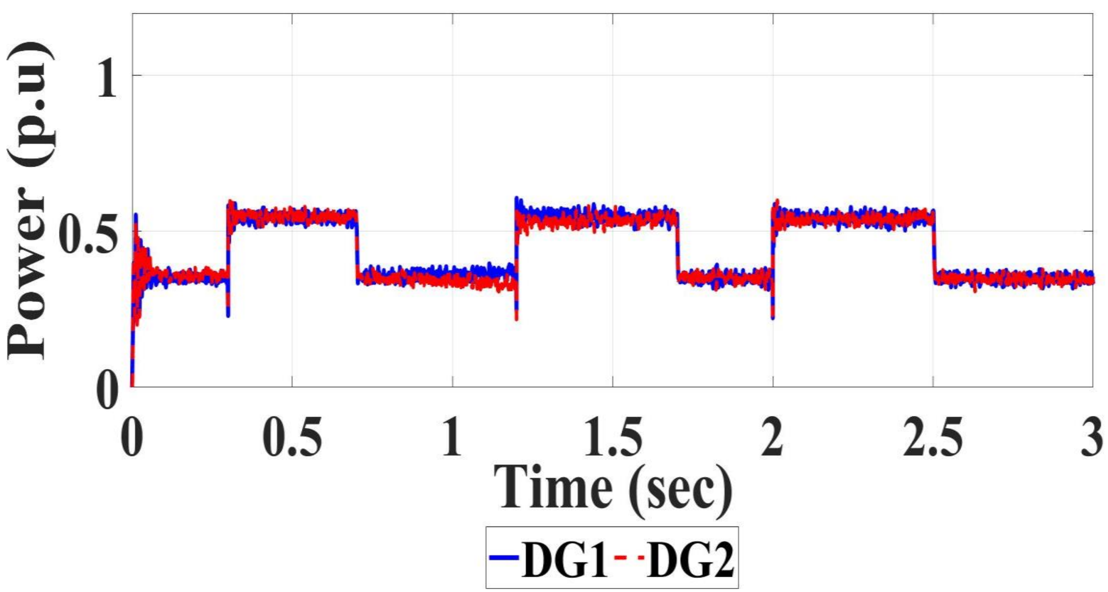


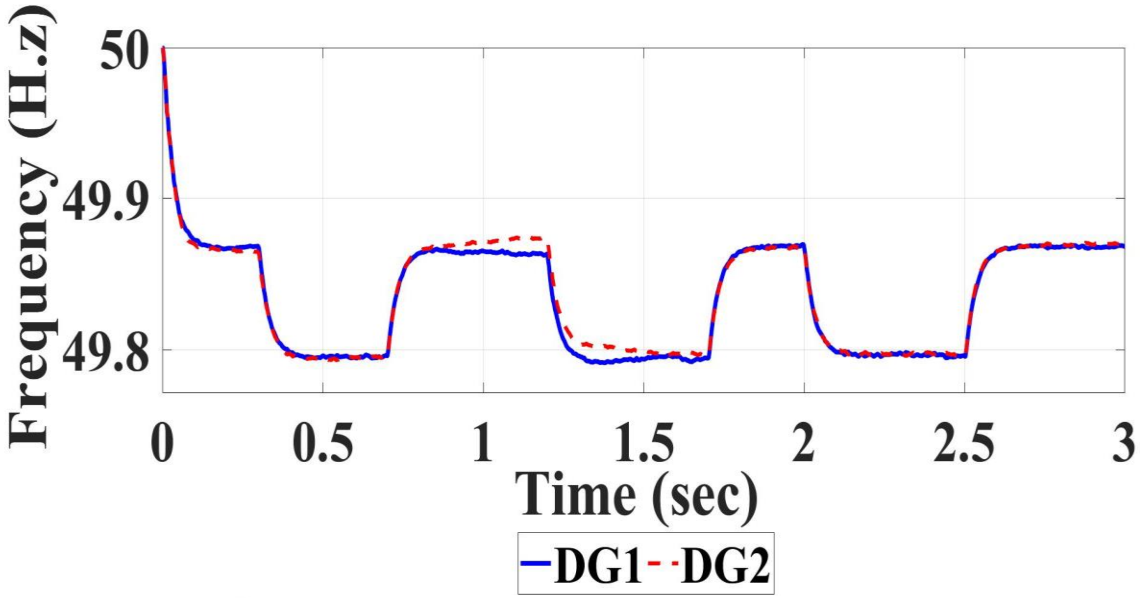


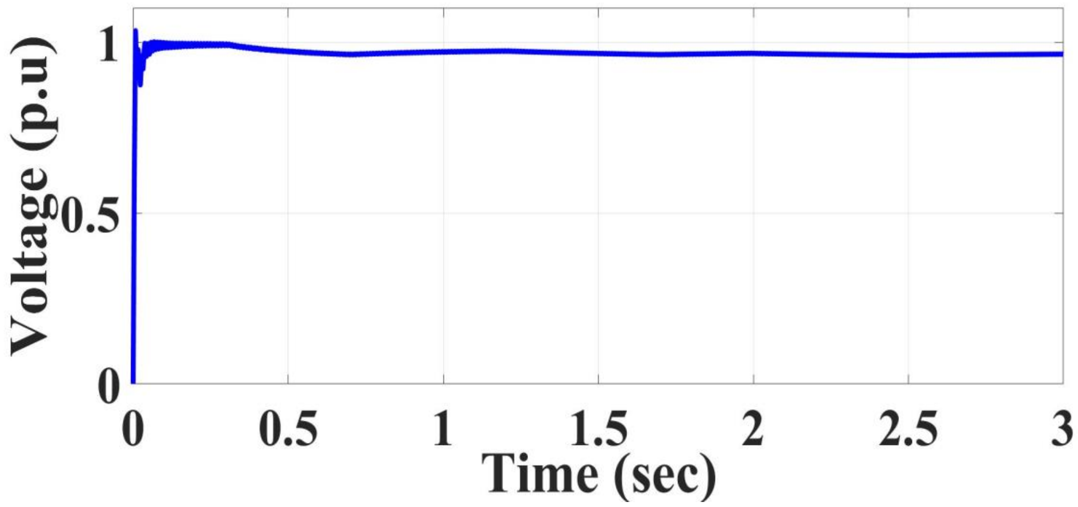


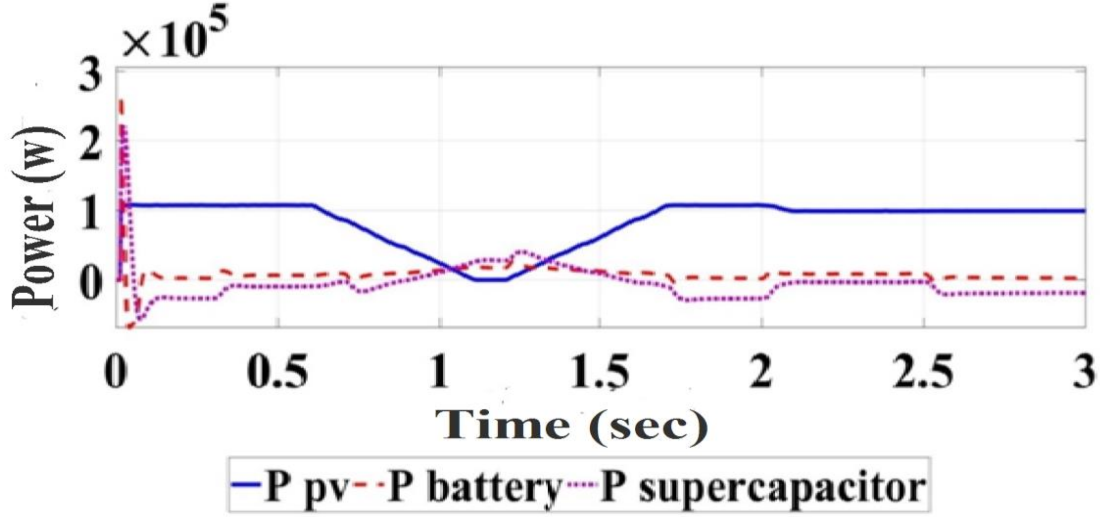


3) Islanding Mode with Continuous Cyclic Load Variations Scenario (IMCCLVS)

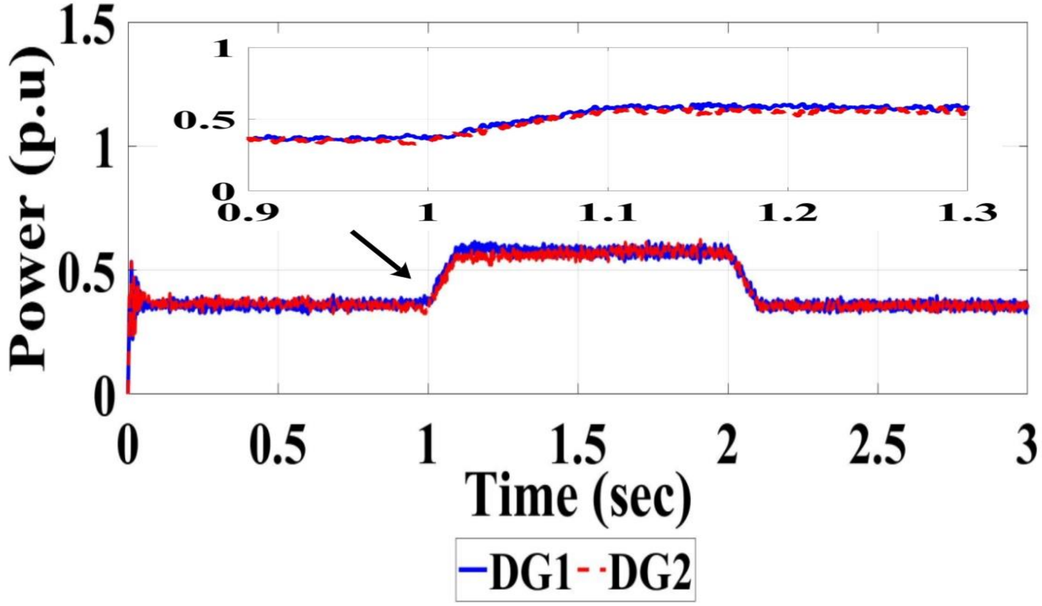


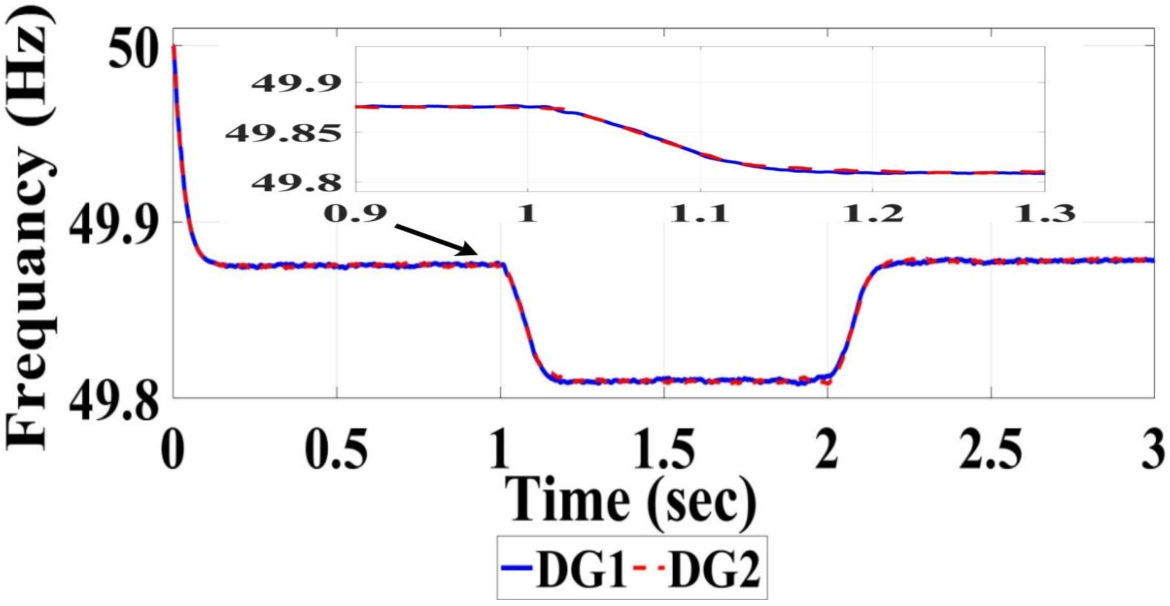


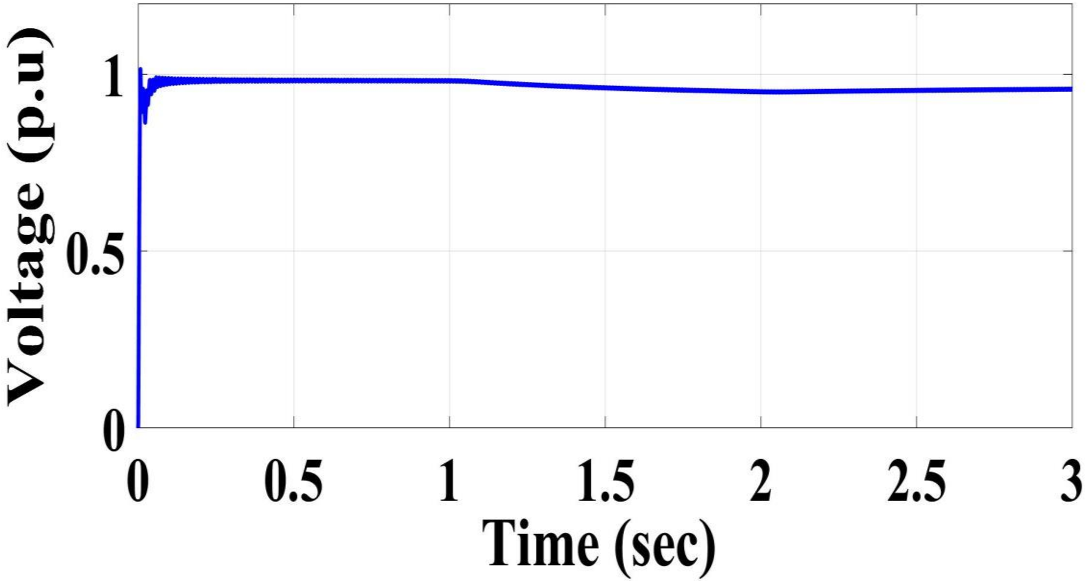


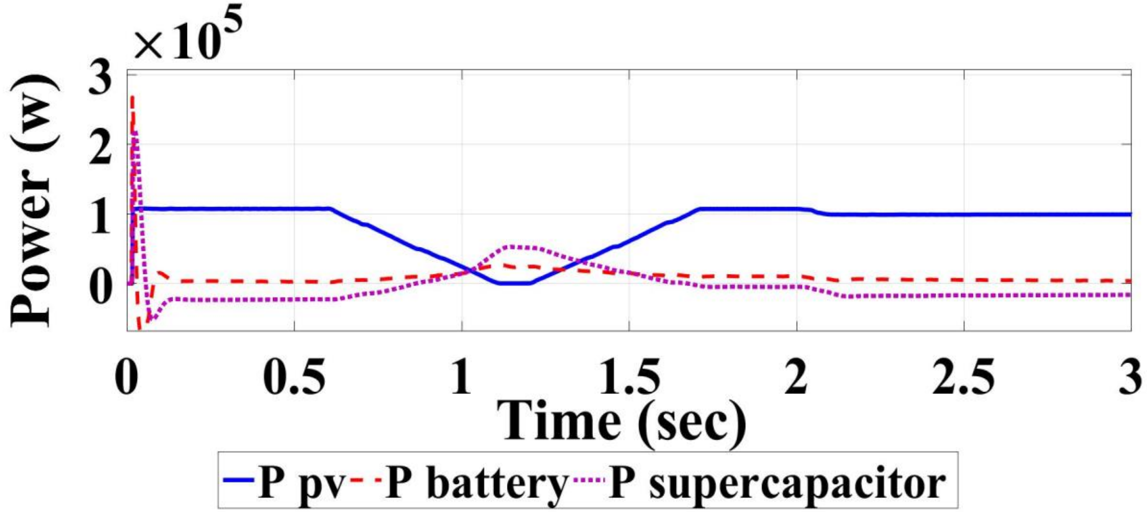


4) Islanding Mode with Ramp Load Variations Scenario (IMRLVS)

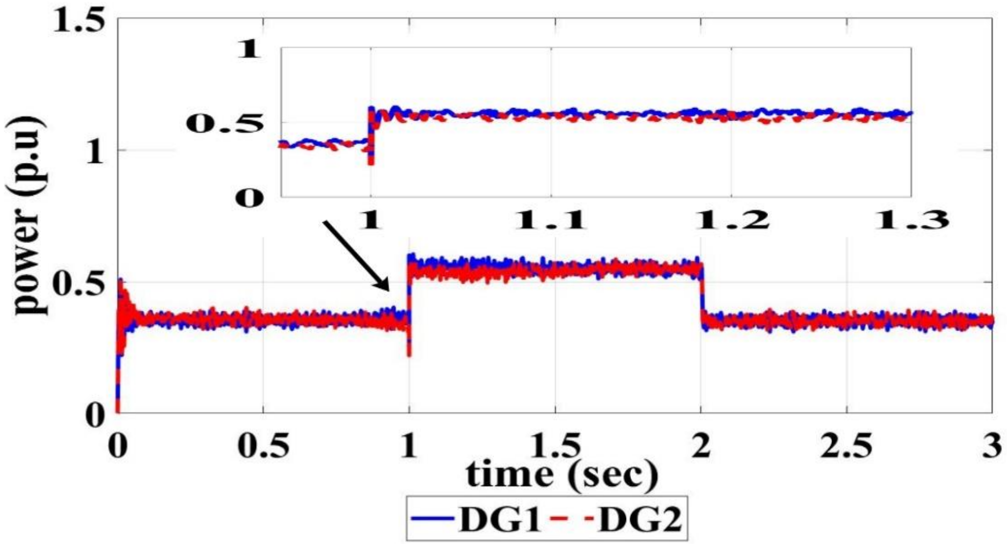


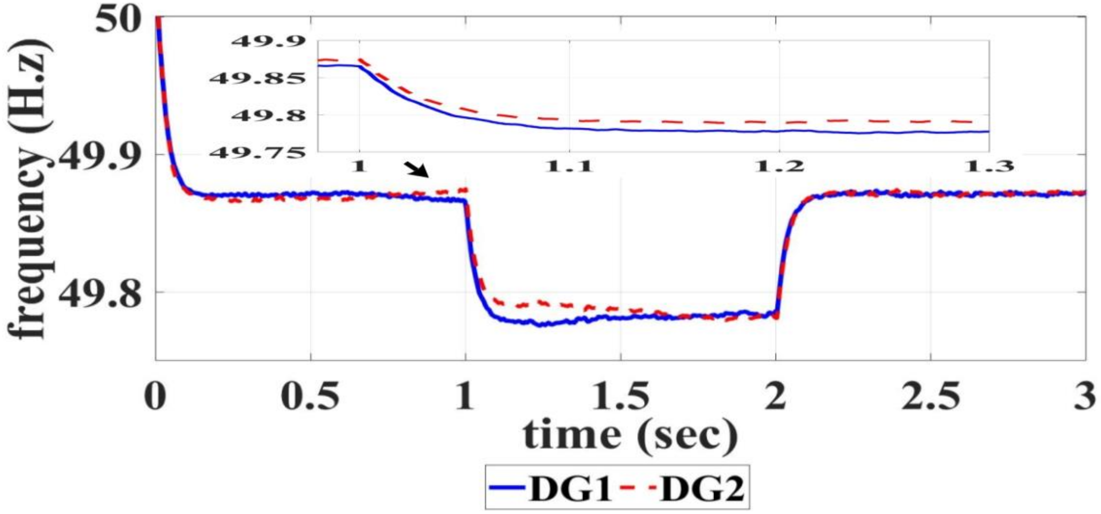


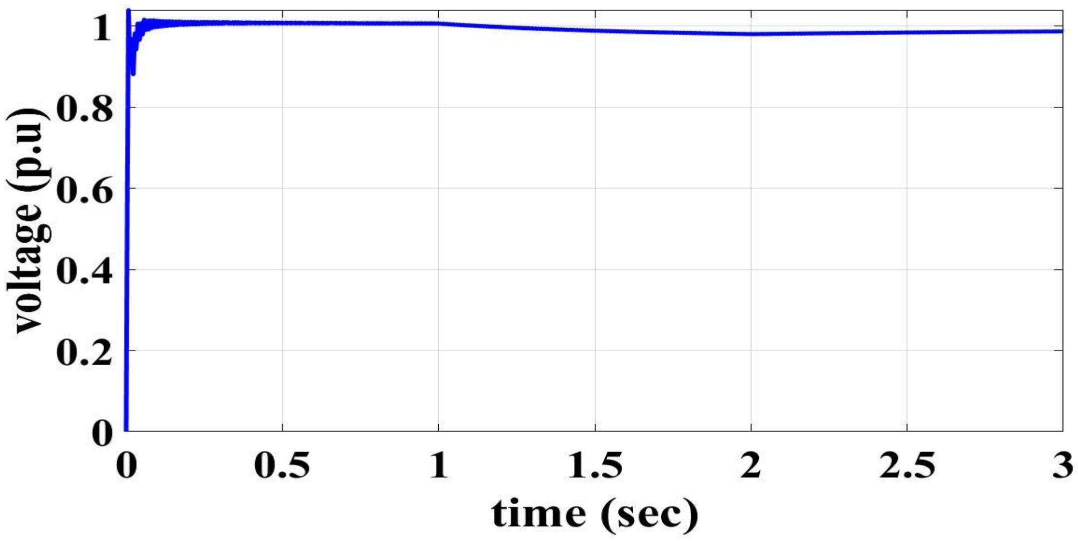


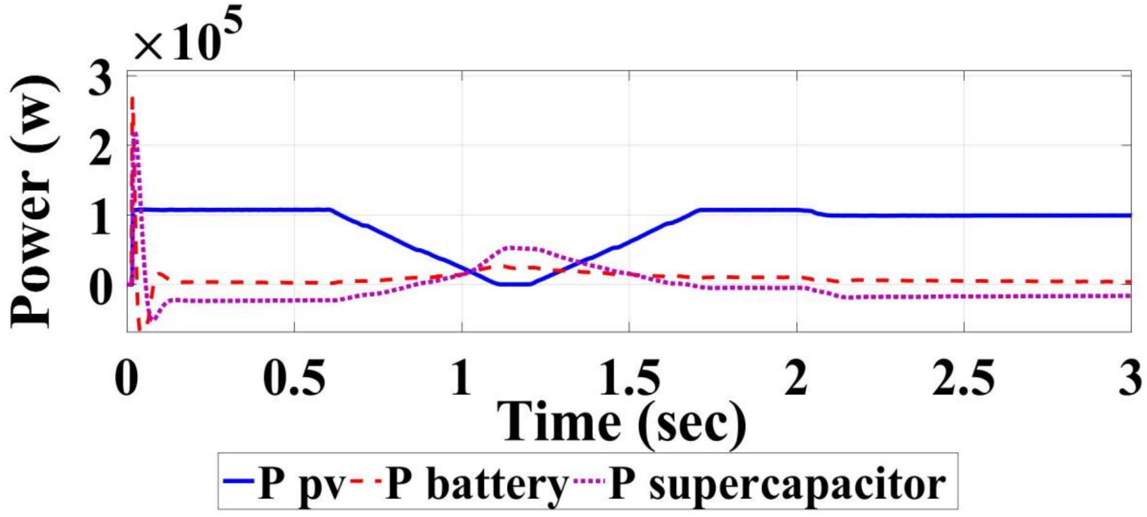


5) Islanding mode with unit step: Uncertainty case 1 (Increasing the PI controllers gains parameters by 20%)

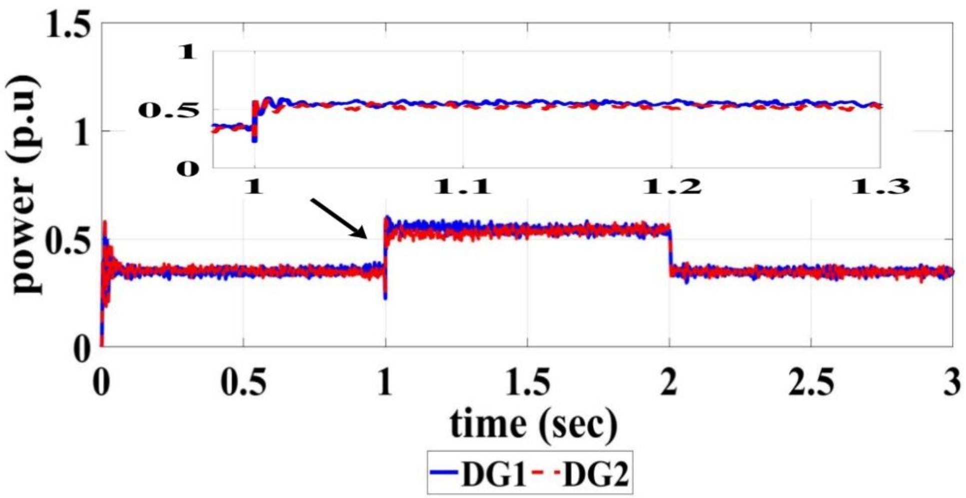


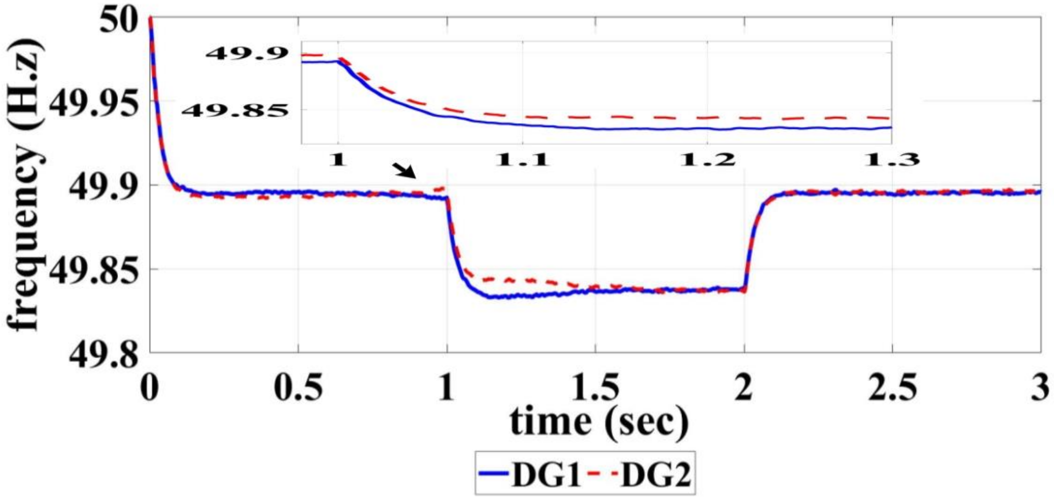


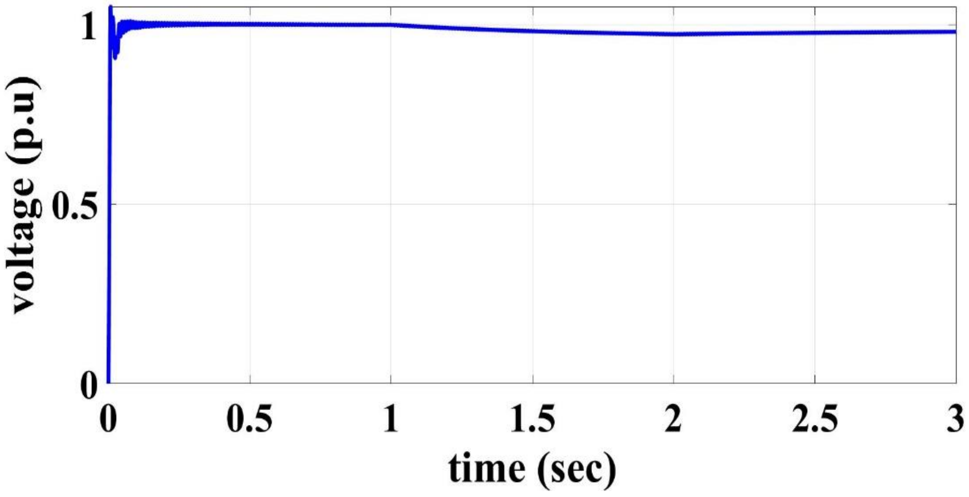


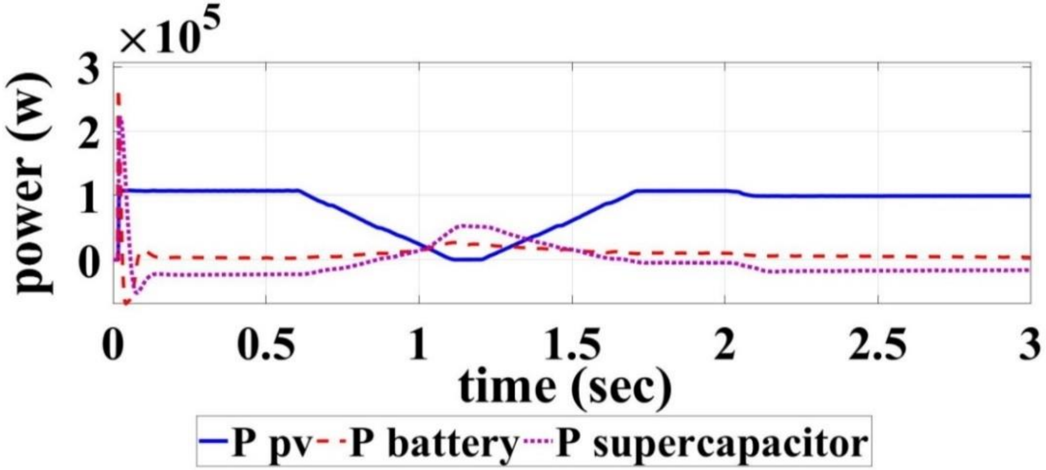


6) Islanding mode with unit step: Uncertainty case 2 (Decreasing the PI controllers gains parameters by 20%)

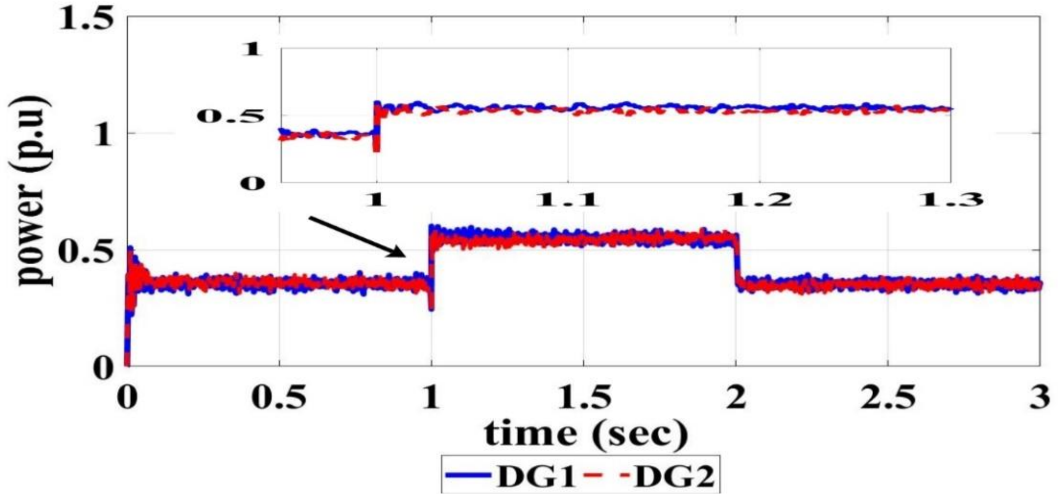


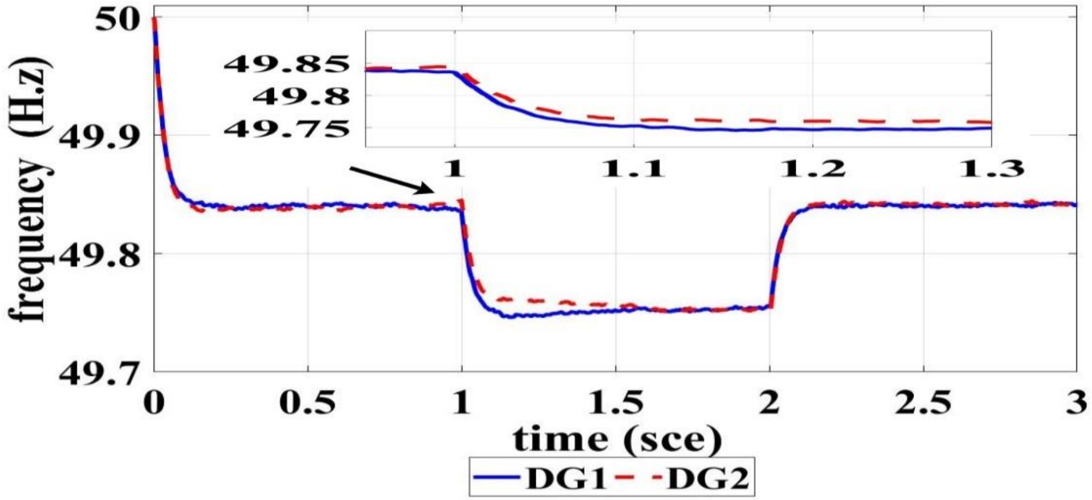


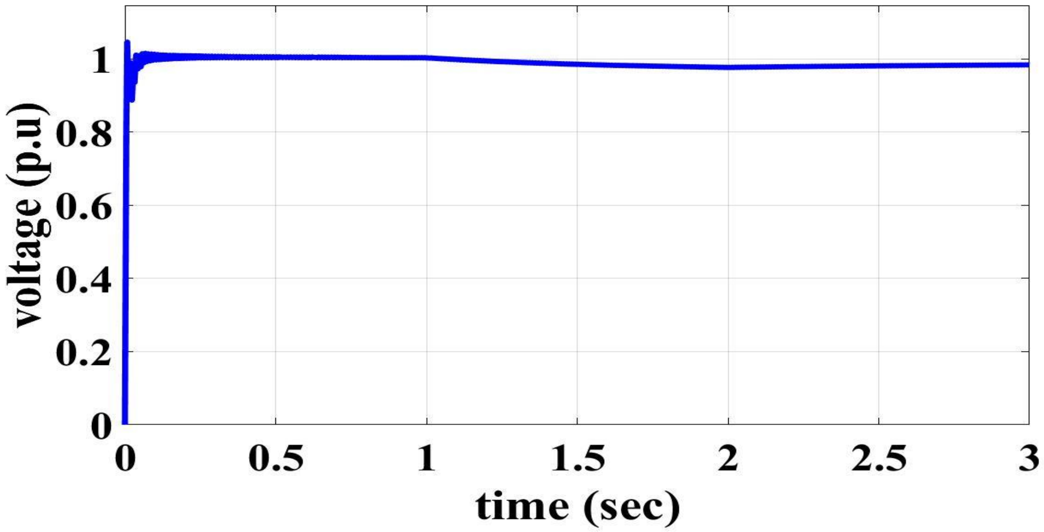


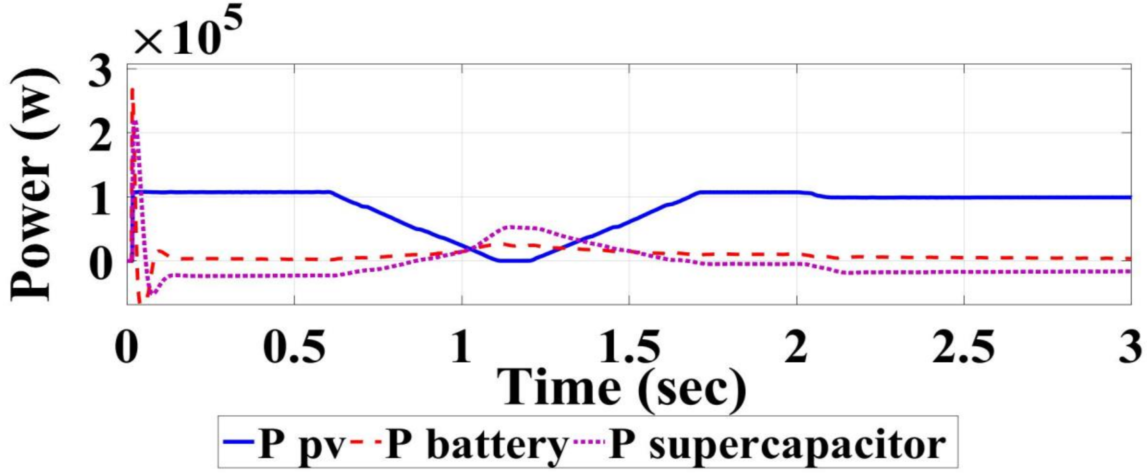


7) Islanding mode with unit step cyclic load variations: Deterioration Scenario#1 (Increasing the parameters of line by 20%)

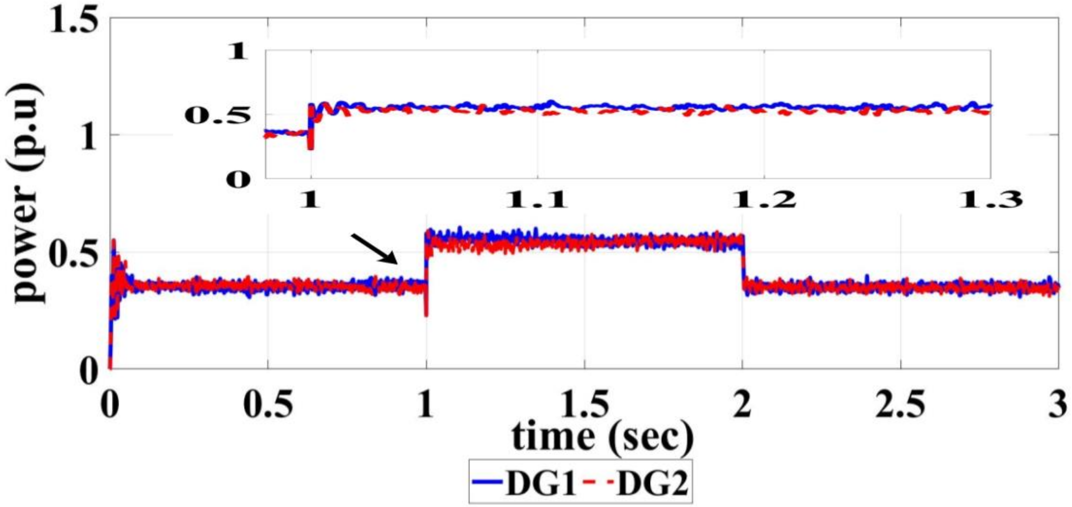


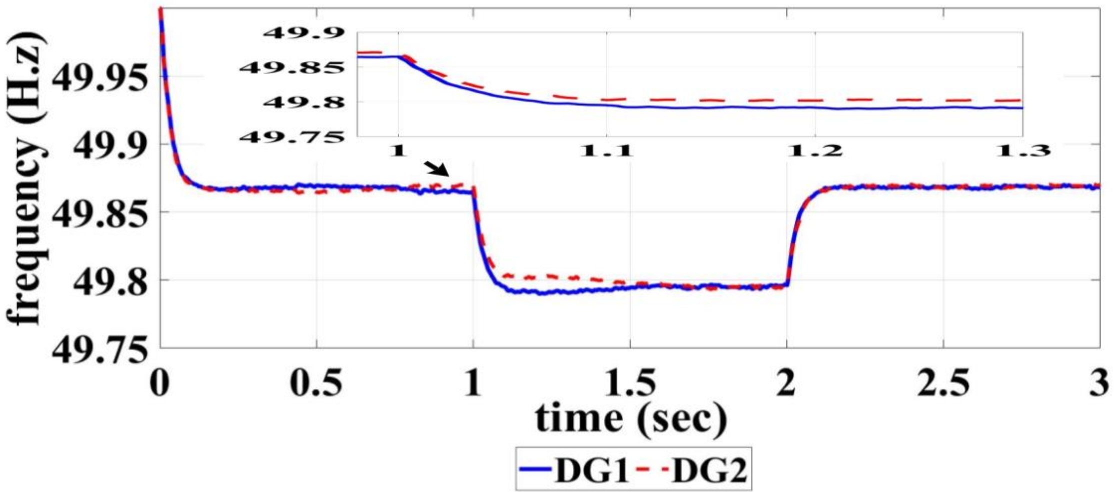


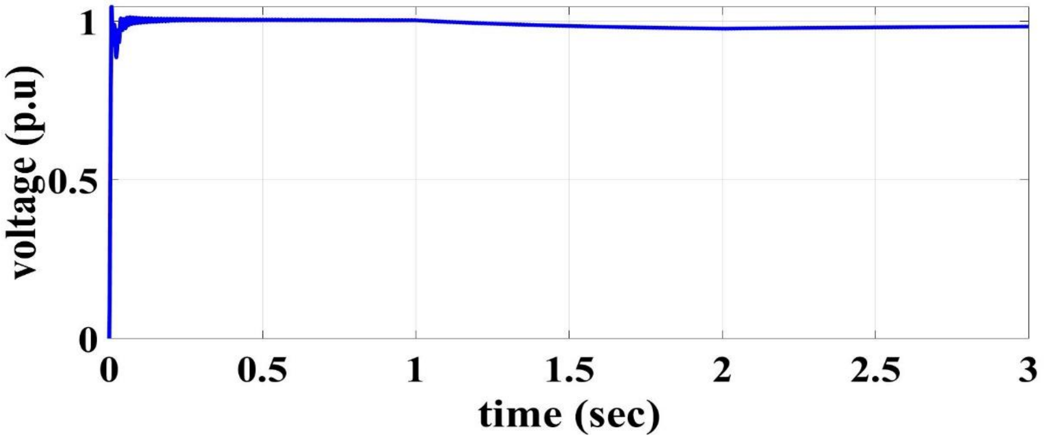


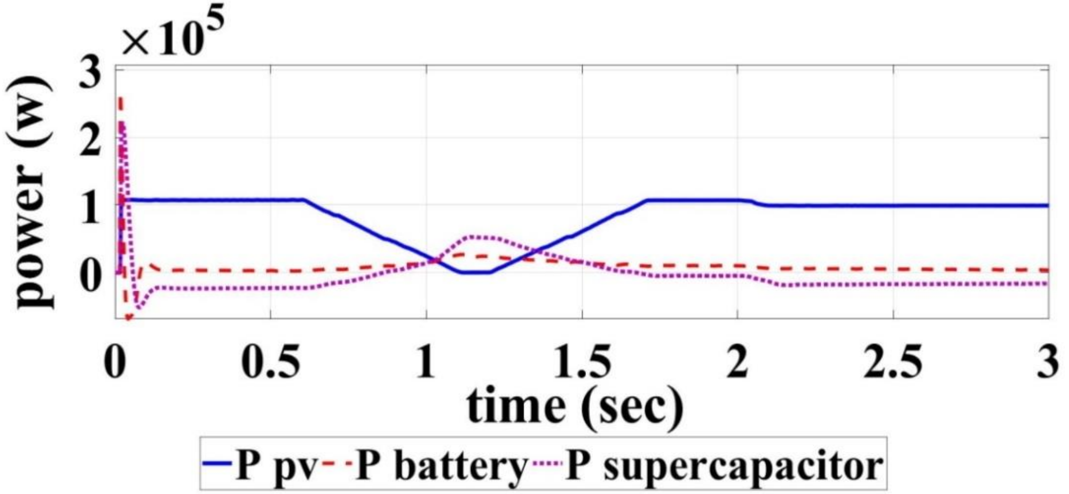


8) Islanding mode with unit step cyclic load variations: Deterioration Scenario# 2 (Decreasing the parameters of line by 20%)

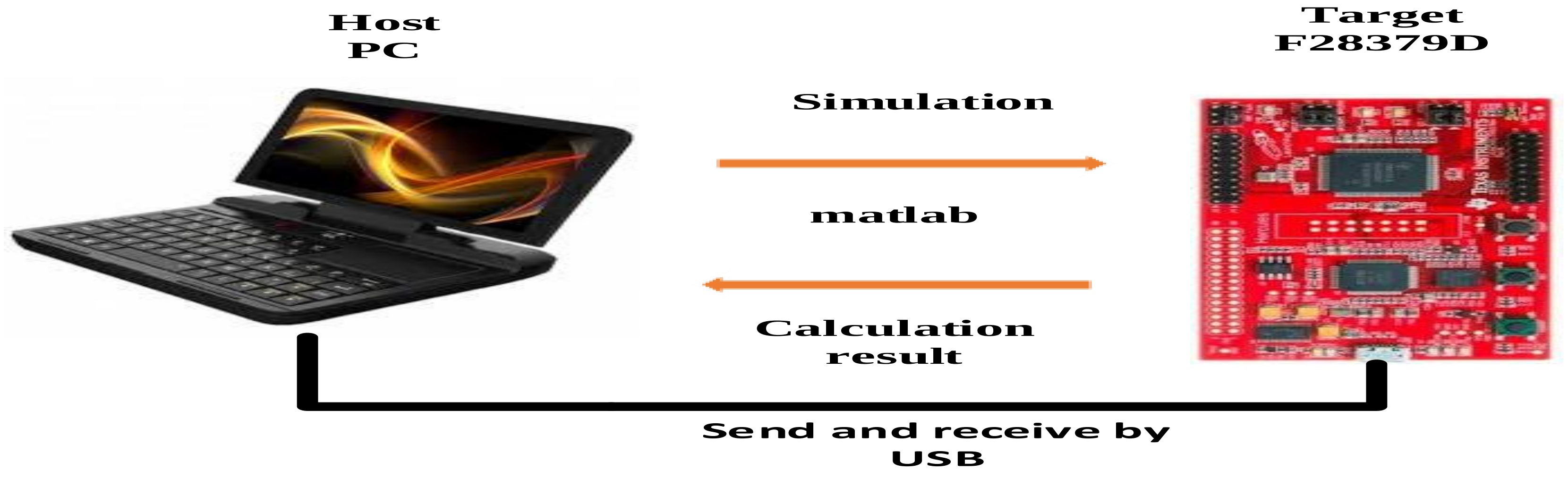


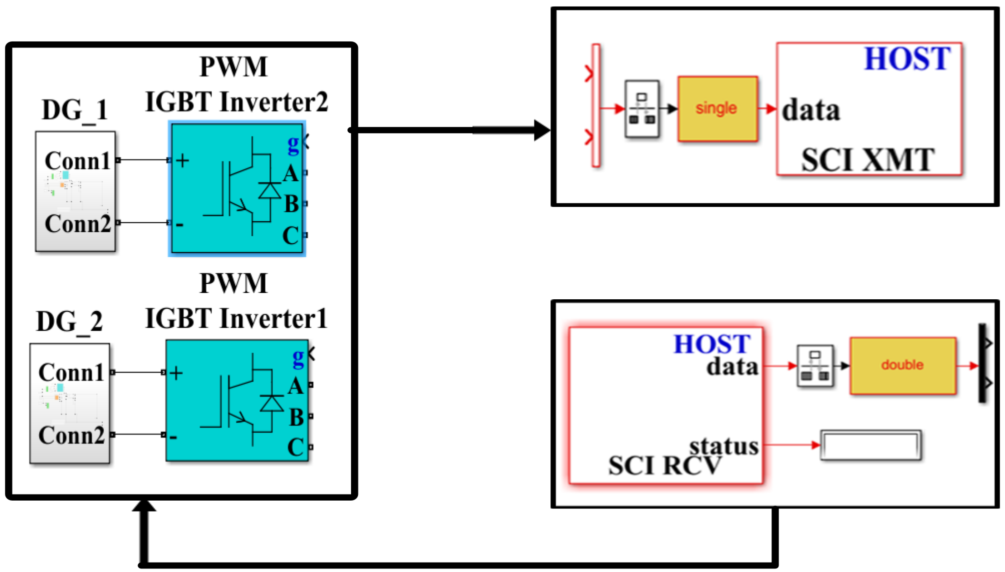




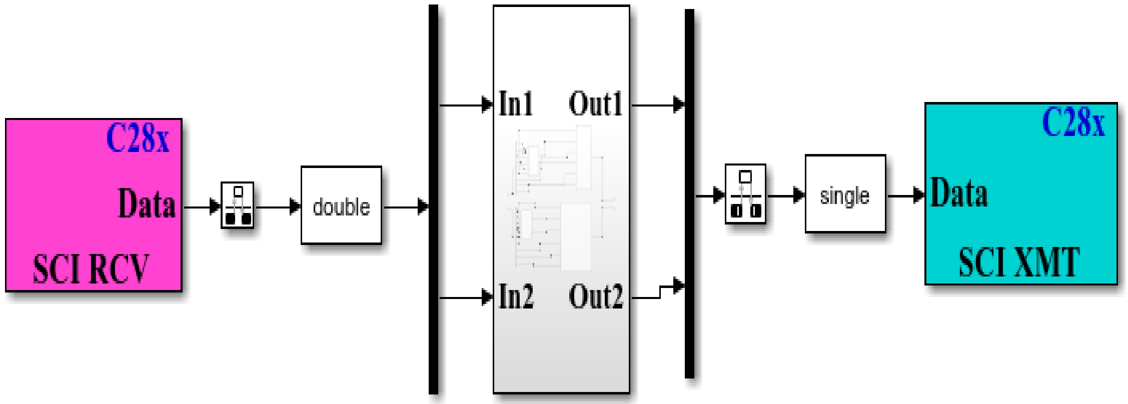


Experimental setup and results

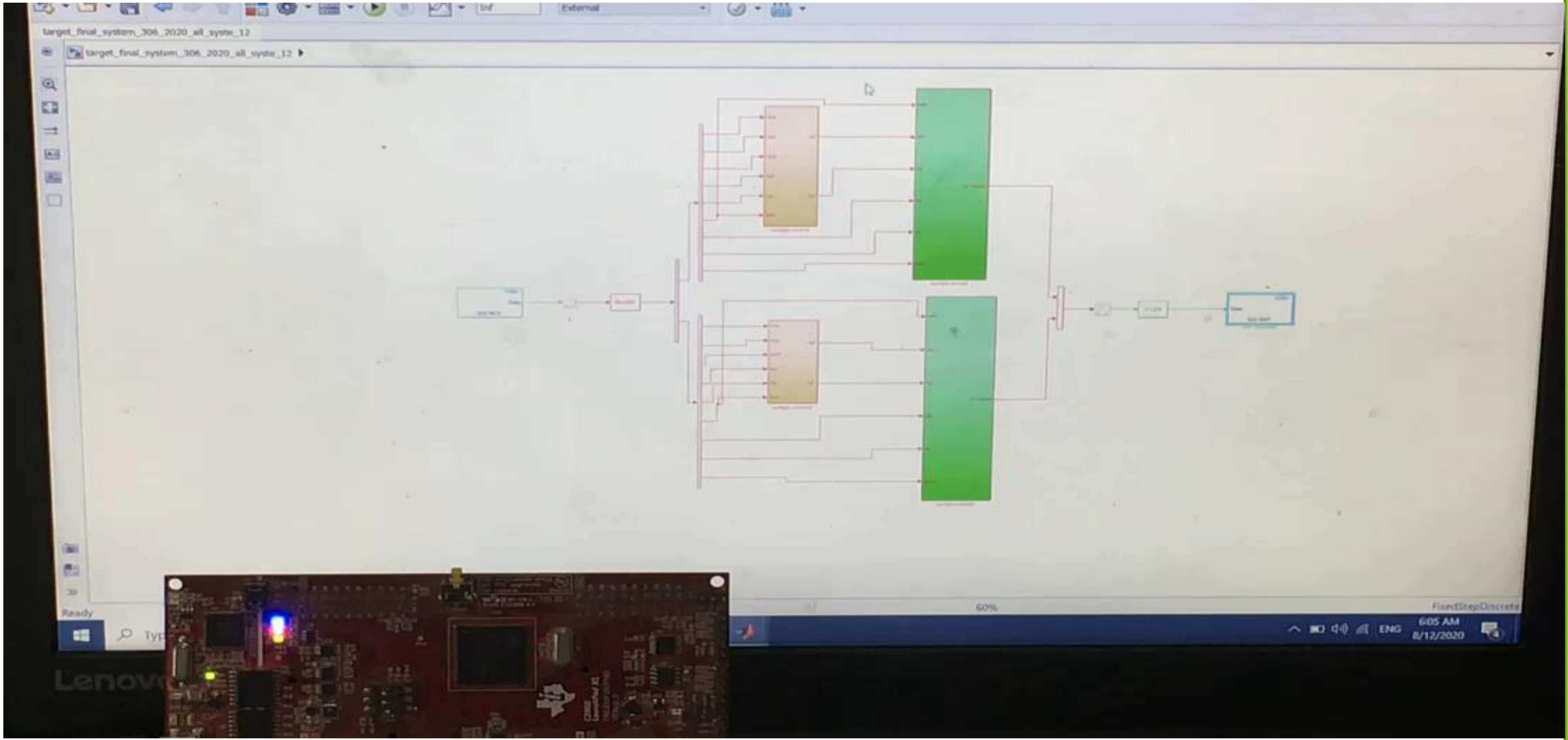




Host PC



Target

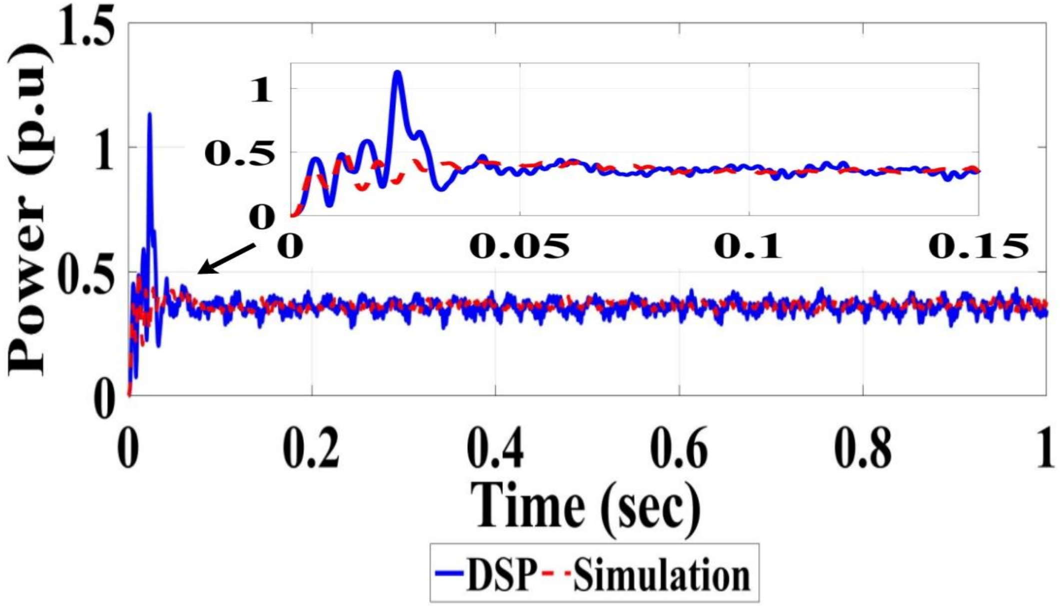

target_final_system_306_2020_all_syste_12
External
Ready
60%
ENG
8/12/2020

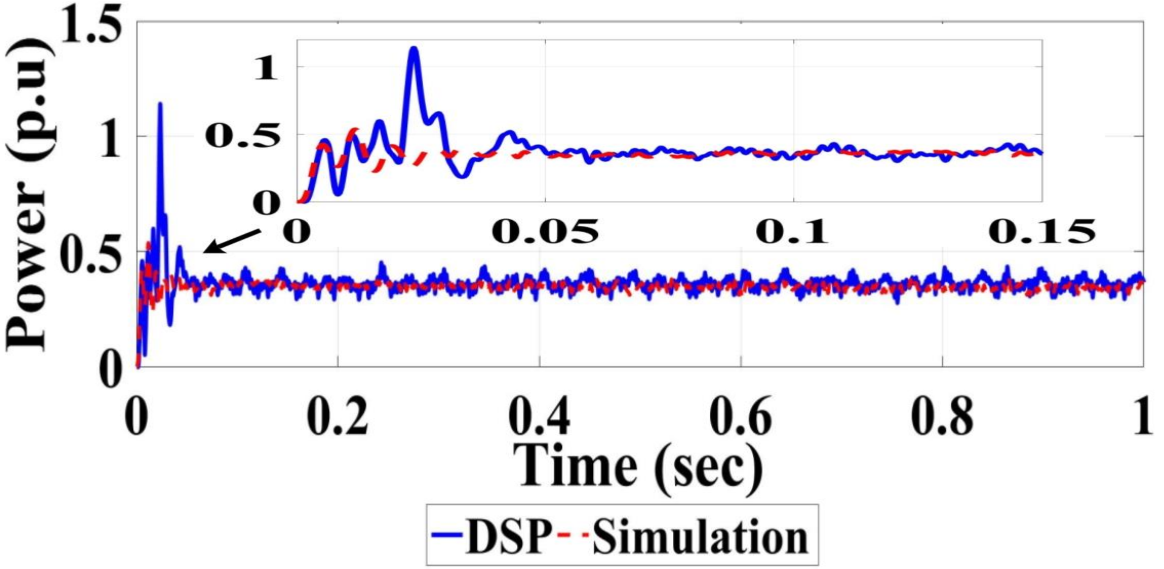
There are two scenarios depending on load effect

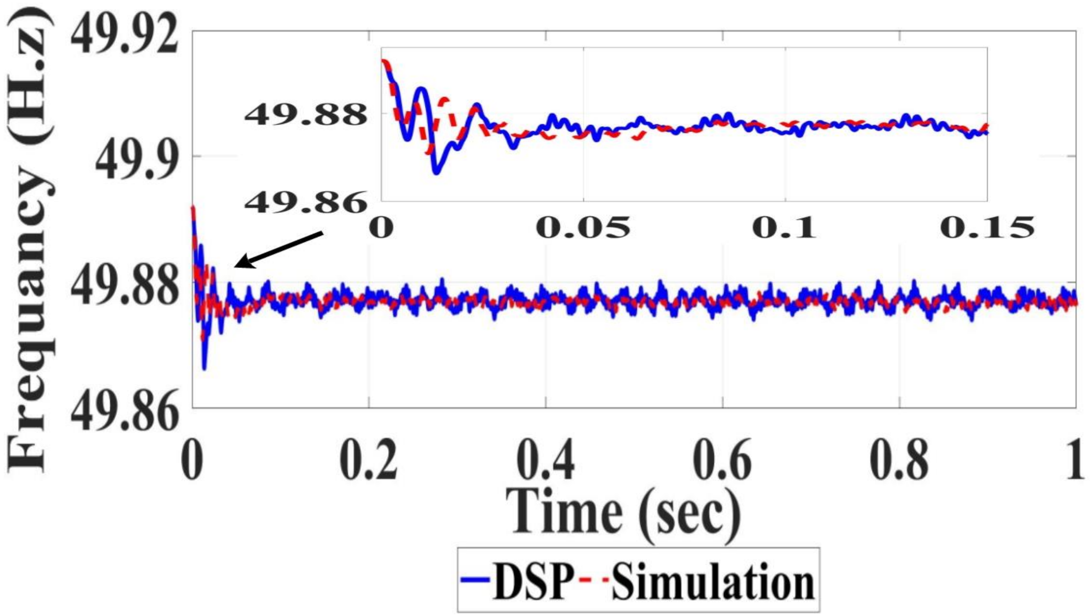
1) Islanding Mode with Fixed Cyclic Load Variations Scenario (IMFCLVS)

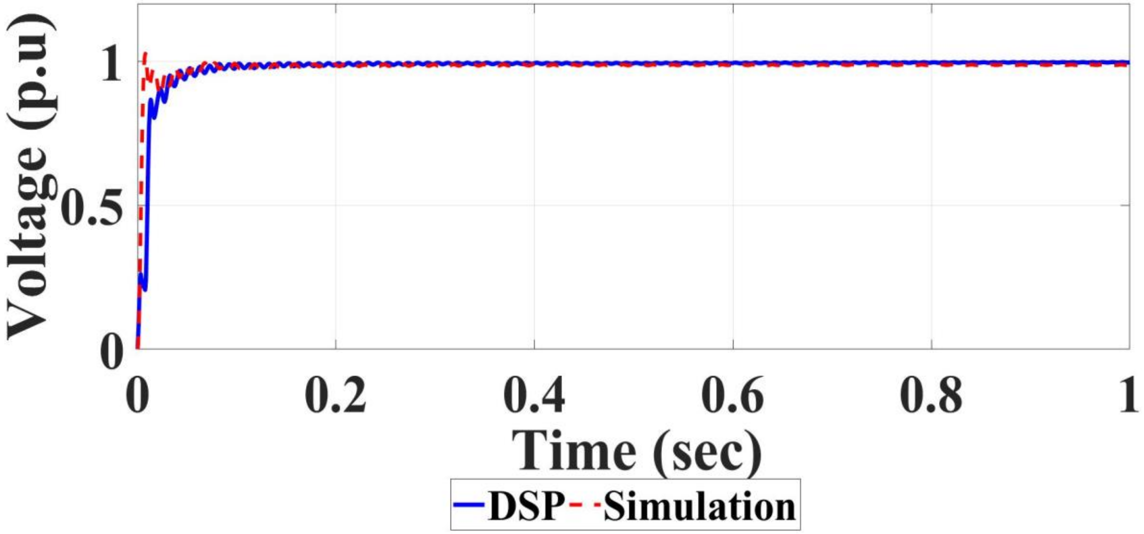
2) Islanding Mode with Cyclic Load Variations Scenario (IMCLVS)

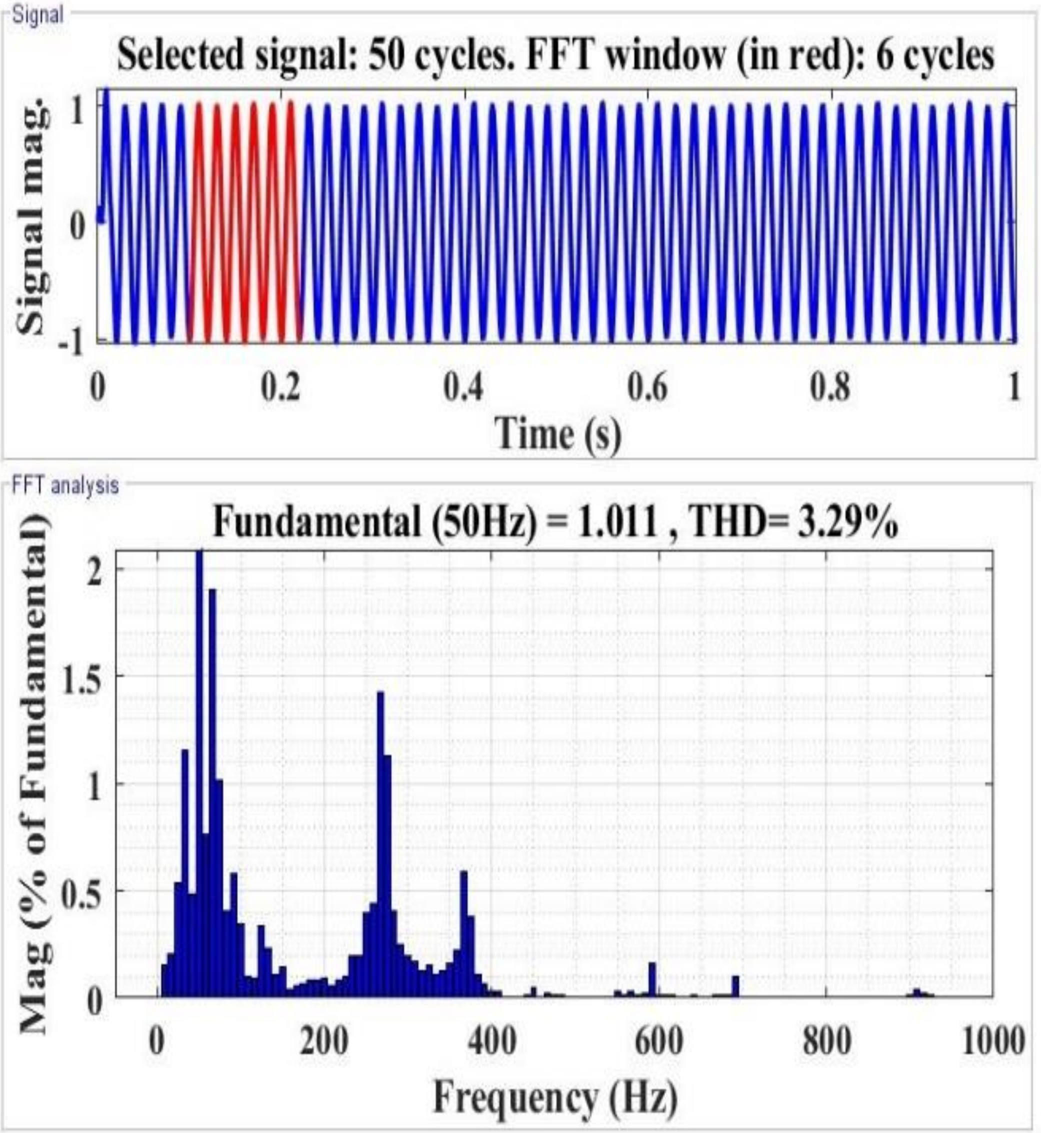
Islanding Mode with Fixed Cyclic Load Variations Scenario (IMFCLVS)



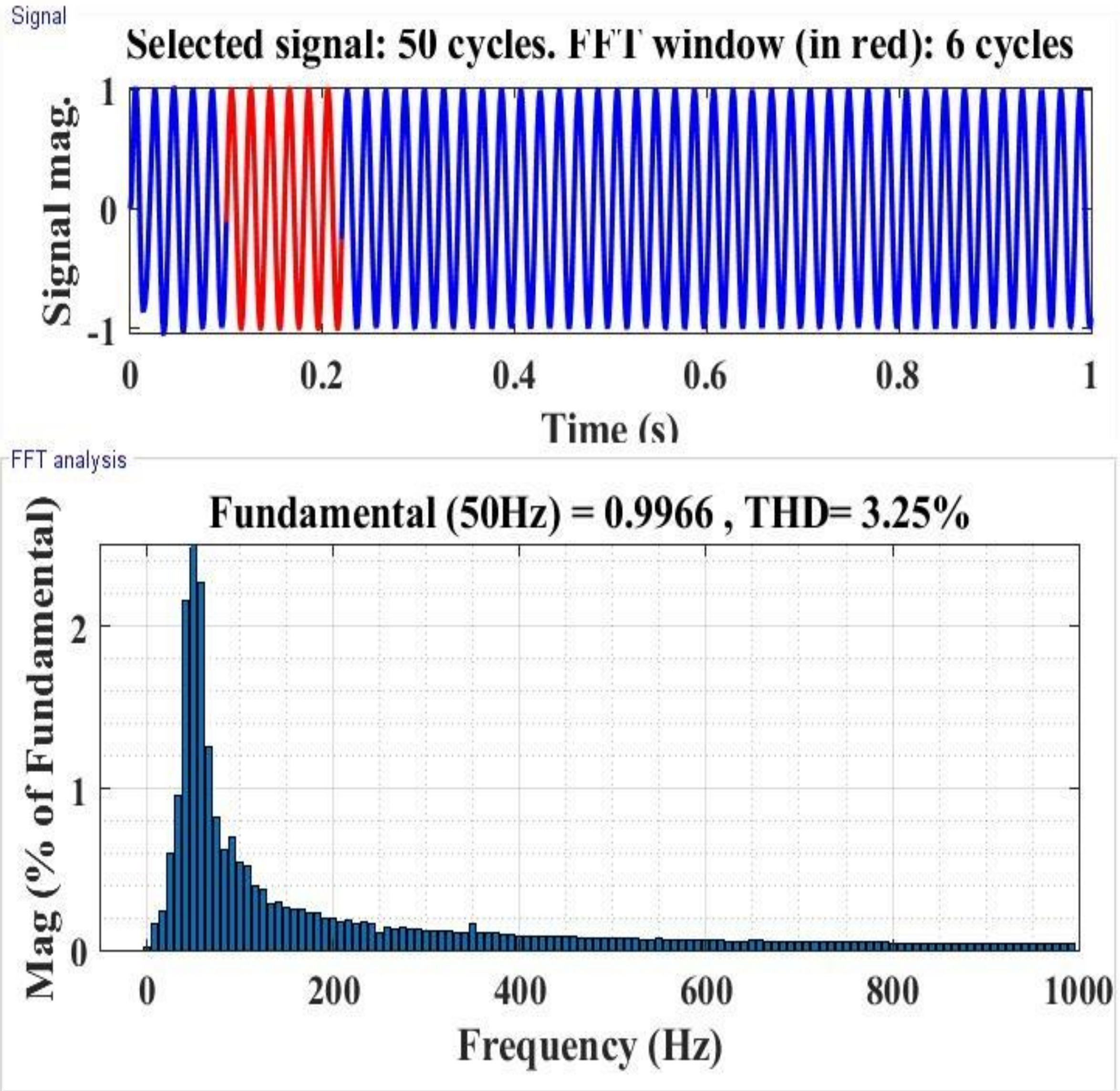






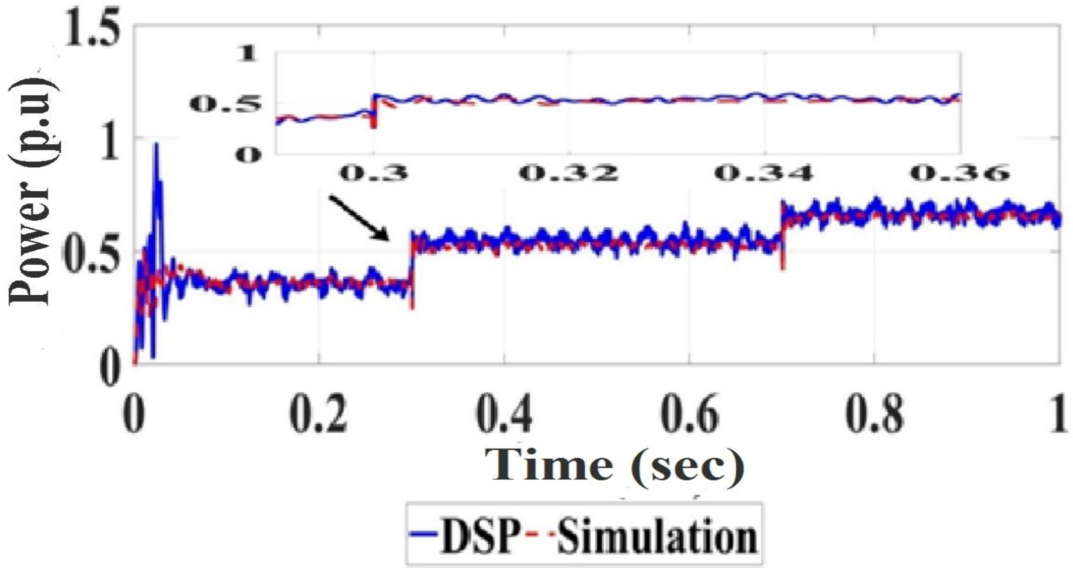


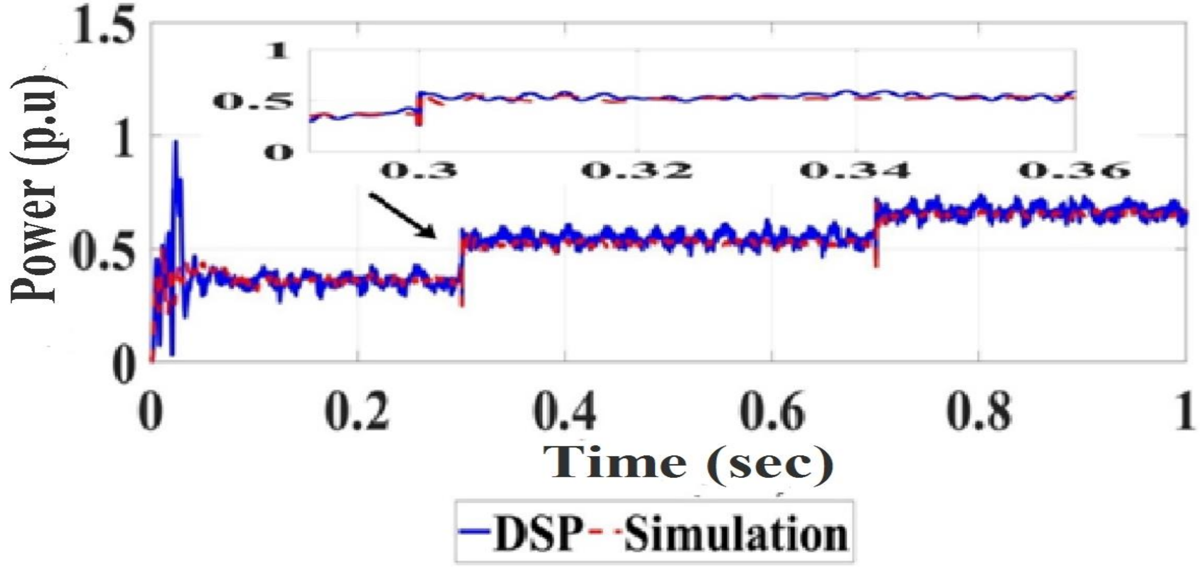
The FFT analysis in DSP of the proposed controller in DSP

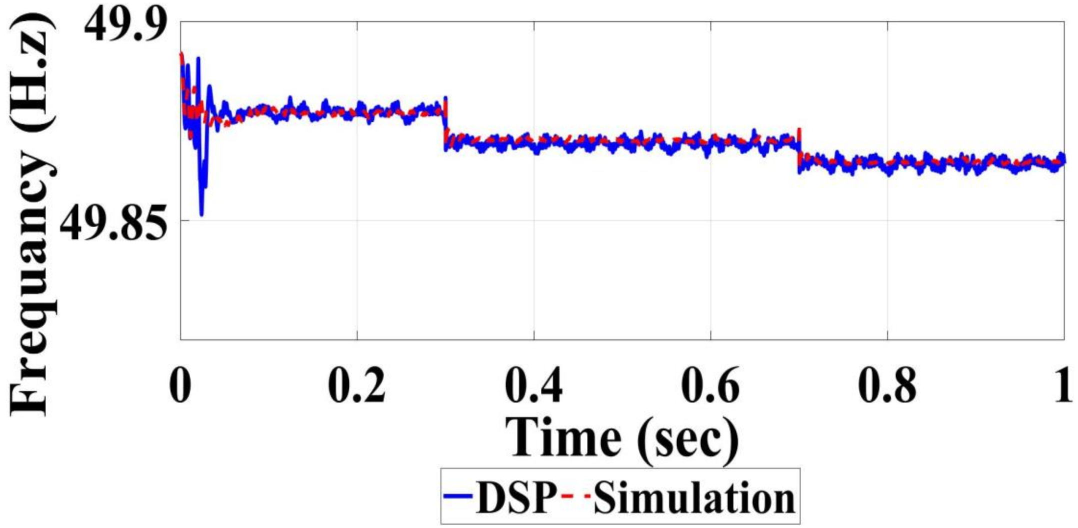


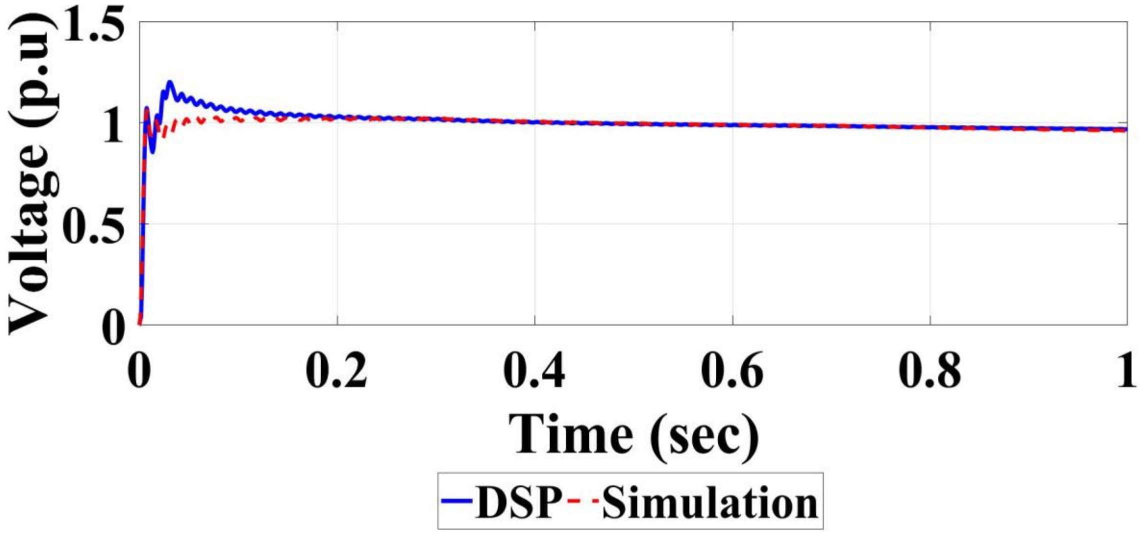
The FFT analysis in simulation of the proposed controller in simulation MATLAB

2) Islanding Mode with Cyclic Load Variations Scenario (IMCLVS)









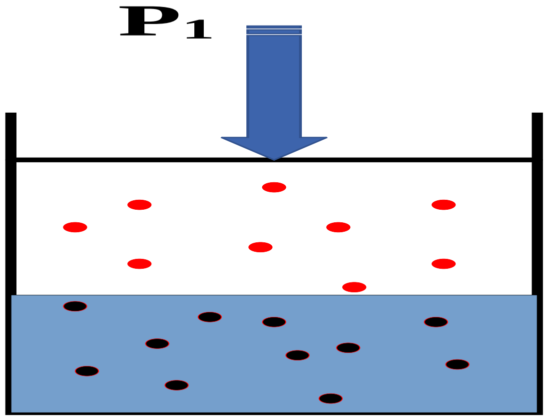
Improved Version of Henry Gas Solubility Optimization

"why do researchers want to discover or develop new algorithms?"

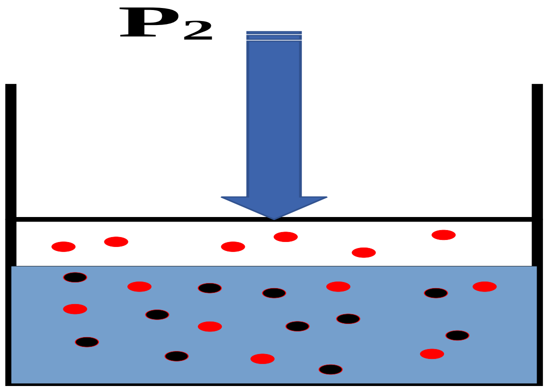
- There is a principle that explains the answer to this issue, which is called the rule of No Free Lunch (NFL) .
- Logically, this principle shows that no one can suggest an algorithm to solve all optimization issues.
- The NFL theory helps researchers to propose new optimization algorithms or strengthen existing algorithms to solve subtypes of problems in different fields.

Henry Gas Solubility Optimization

- In 2019, a new mathematical model called HGSO, which relies on Henry's Law simulations to solve optimization problems, was proposed by Fatma et al.
- In 1803, William Henry proposed the law of Henry, a law on gas.
- The Law of Henry states that; "At a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid".



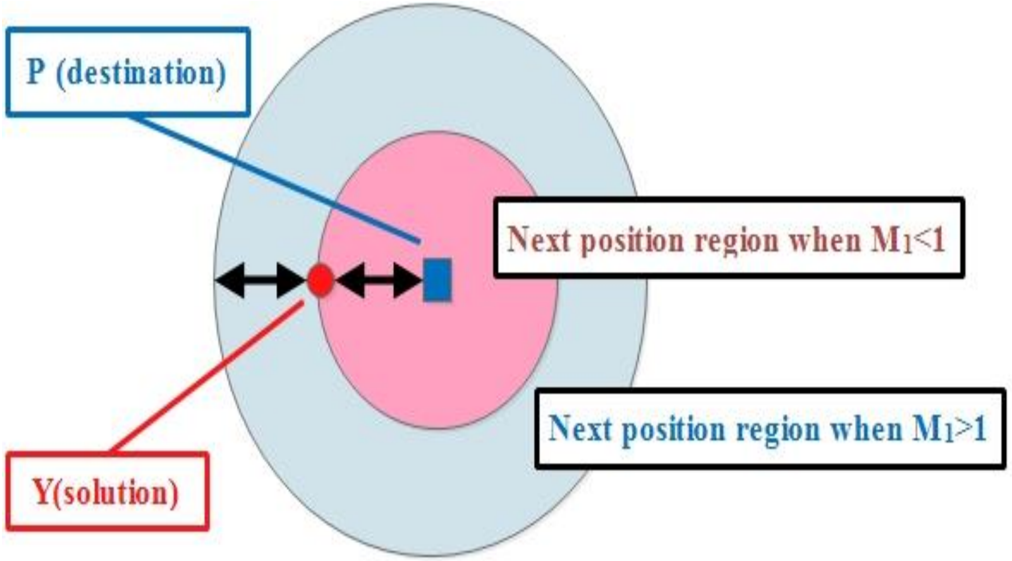
a) A saturated solution of a gas is in equilibrium at pressure p1

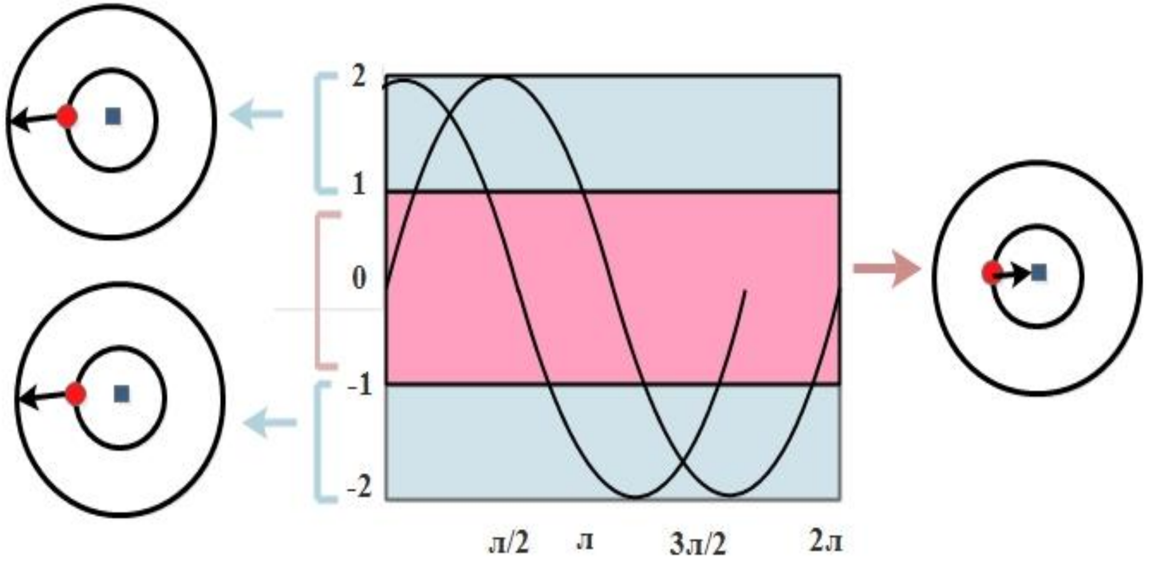


b) if the pressure is increased to p2, the volume of the gas decreases

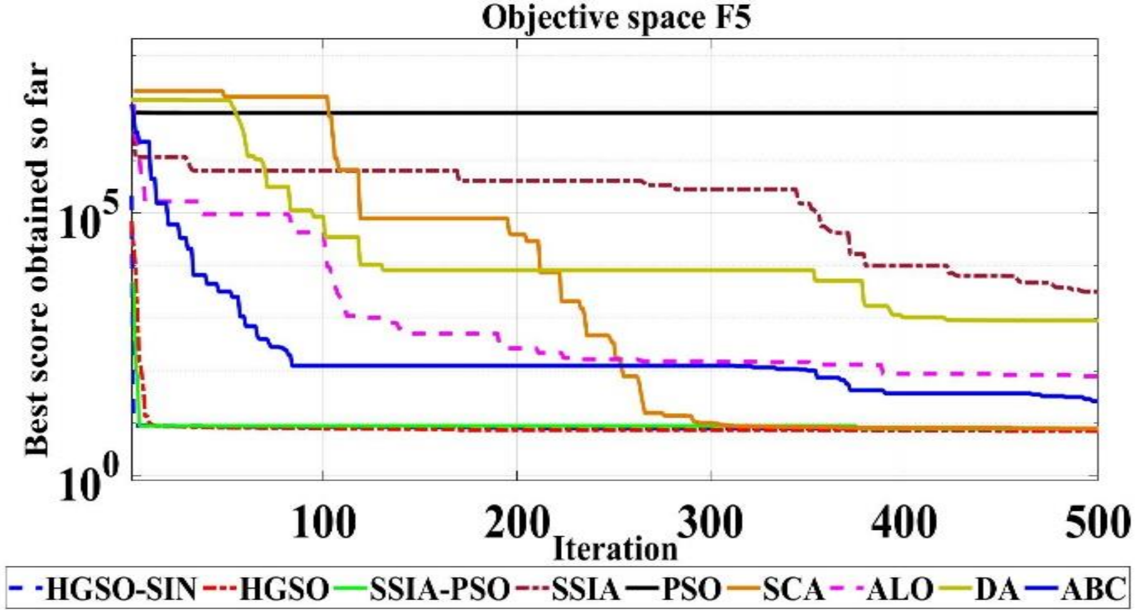
A Sine Cosine Algorithm

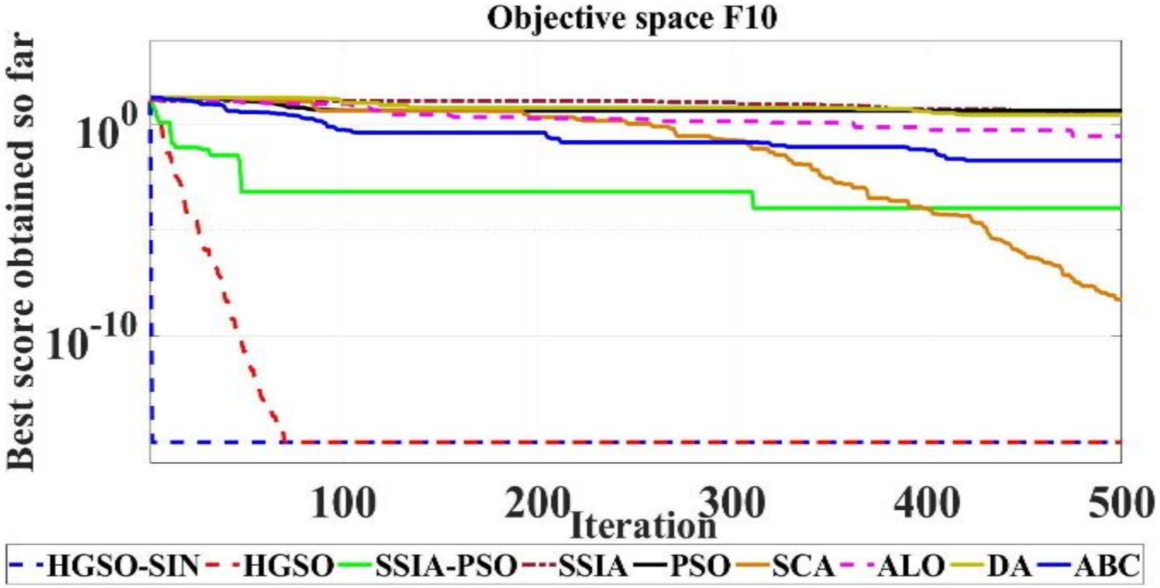
- A new swarm intelligence optimization algorithm proposed by Mirjalili in 2016 is the Sine-cosine algorithm (SCA).
- the Sine Cosine Algorithm (SCA) is implemented simply based on the Sine and Cosine function.
- The Sine Cosine Algorithm (SCA) generates various initial random agent solutions and allows them to use a mathematical model based on sine and cosine functions to fluctuate outward or toward the best possible solution.

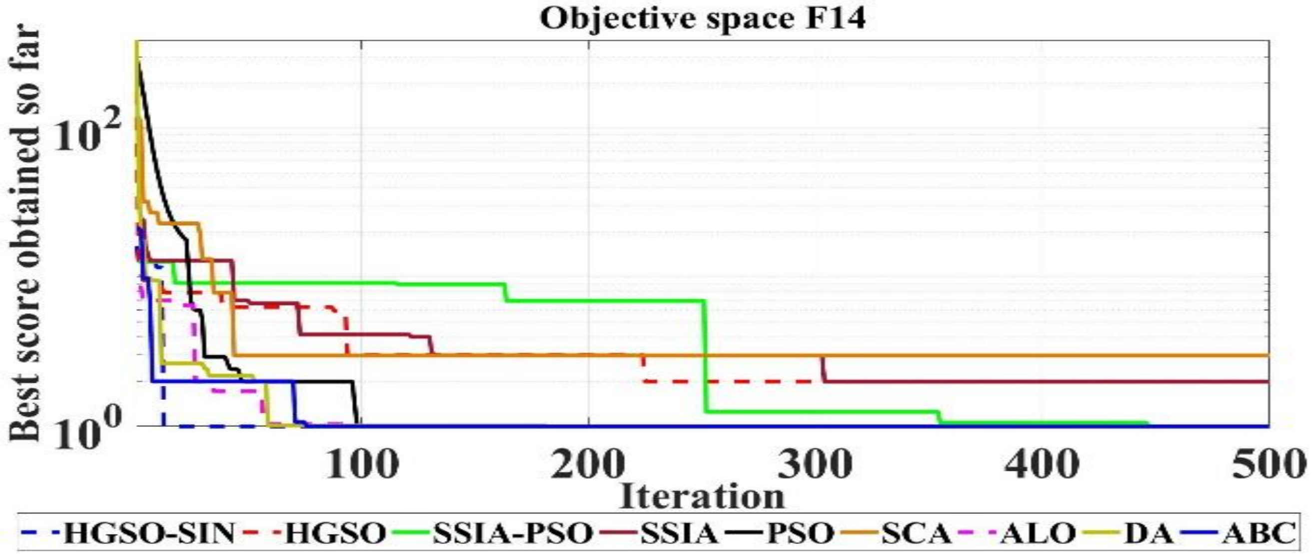


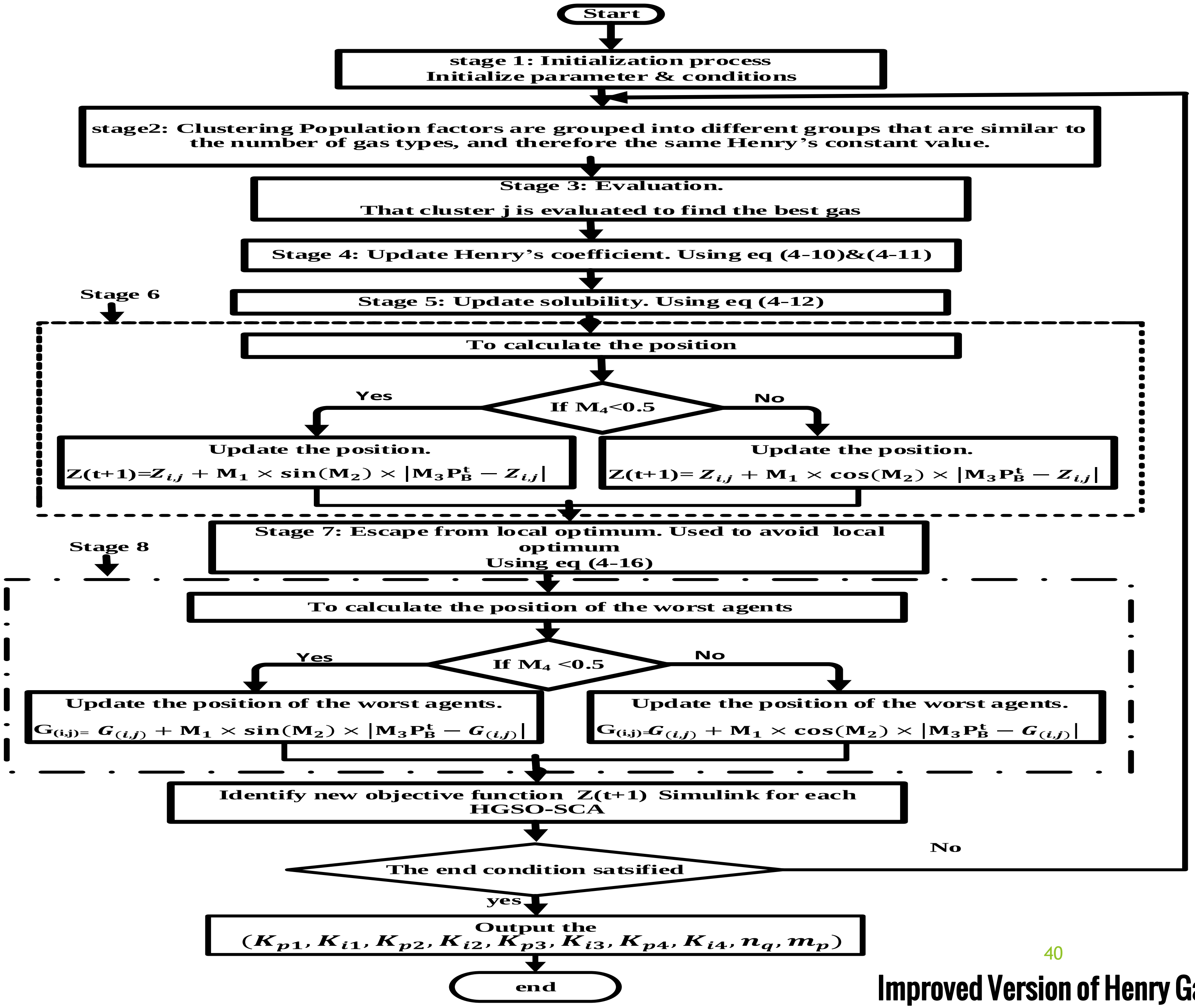


Improved Version of Henry Gas Solubility Optimization



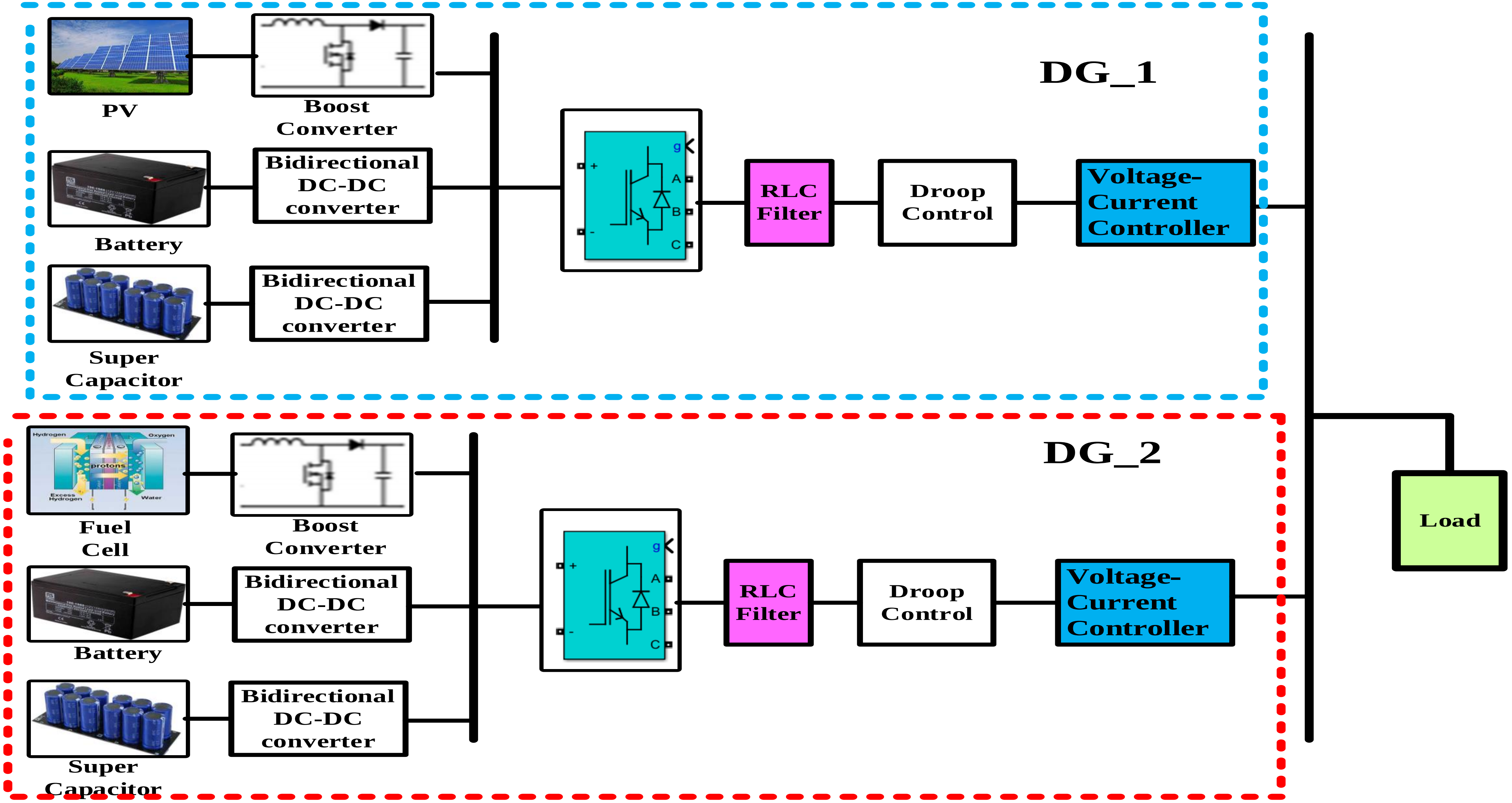






Improved Version of Henry Gas Solubility Optimization

Test Functions		HGSO-SIN	HGSO	SSIA-PSO	SSIA	PSO	SCA	ALO	DA	ABC
F1	Average	0	0	$1.75x10^{-18}$	$1.64 x10^{-07}$	$1.82 x10^{04}$	$1.18 x10^{-02}$	$6.83x10^{-06}$	$4.25x10^{0}$	$1.46 x10^{-2}$
	Std	0	0	$8.86x10^{-18}$	$2.47 x10^{-07}$	$2.30 x10^{04}$	$5.59 x10^{-02}$	$7.21x10^{-06}$	$3.82x10^{0}$	$2.08x10^{-2}$
F2	Average	0	$8.87 x10^{-201}$	$3.04x10^{-11}$	$3.11 x10^{-03}$	$1.36 x10^{0}$	$8.56x10^{-04}$	$3.58x10^{0}$	$5.66x10^{0}$	$2.433x10^{-3}$
	Std	0	0	$5.91x10^{-11}$	$7.94 x10^{-3}$	$3.53 x10^{0}$	$1.06x10^{-03}$	$5.58x10^{0}$	$4.63x10^{0}$	$1.53x10^{-3}$
F3	Average	0	0	$1.04 x10^{-19}$	$4.81 x10^{-06}$	$5.329 x10^{03}$	$2.53 x10^{01}$	$3.09x10^{02}$	$2.46 x10^{01}$	$5.33 x10^{02}$
	Std	0	0	$3.33x10^{-19}$	$2.02 x10^{-05}$	$5.58 x10^{03}$	$6.17 x10^{01}$	$3.01x10^{02}$	$2.51x10^{01}$	$2.75x10^{02}$
F4	Average	0	$2.12 x10^{-202}$	$2.51 x10^{-11}$	$2.02 x10^{-05}$	$2.71 x10^{01}$	$5.58 x10^{-01}$	$1.32x10^{0}$	$5.67x10^{-01}$	$5.32x10^{0}$
	Std	0	0	$8.25 x10^{-11}$	$6.65 x10^{-06}$	$2.38 x10^{01}$	$7.80x10^{-01}$	$1.83x 10^{0}$	$2.90x10^{-01}$	$1.17x 10^{0}$
F5	Average	$7.09 x10^{0}$	$7.27 x10^{0}$	$8.89 x10^{0}$	$9.55 x10^{01}$	$1.42 x10^{05}$	$3.14 x10^{01}$	$1.81x10^{02}$	$5.03x10^{02}$	$1.74x10^{02}$
	Std	$2.05 x10^{-01}$	$3.98 x10^{-01}$	$1.35 x10^{-02}$	$1.50 x10^{02}$	$7.50 x10^{05}$	$1.23 x10^{02}$	$4.48x10^{02}$	$4.18x10^{02}$	$1.62x10^{02}$
F6	Average	$6.90 x10^{-02}$	$2.09 x10^{-01}$	$1.07 x10^{0}$	$9.34x10^{-10}$	$2.69 x10^{03}$	$6.20x10^{-01}$	$1.18x10^{-05}$	$5.64x10^{0}$	$1.49x10^{-02}$
	Std	$2.32x10^{-02}$	$1.35 x10^{-01}$	$2.85 x10^{-01}$	$3.37 x10^{-10}$	$4.56 x10^{03}$	$1.98 x10^{-01}$	$1.24x10^{-05}$	$3.76x10^{0}$	$1.89x10^{-02}$
F7	Average	$3.88x10^{-05}$	$4.63 x10^{-05}$	$2.73 x10^{-04}$	$1.32 x10^{-02}$	$1.61 x10^{-02}$	$8.36 x10^{-03}$	$6.59x10^{-02}$	$2.69x10^{-01}$	$2.38x10^{-02}$
	Std	$3.71x10^{-05}$	$4.04 x10^{-05}$	$2.61 x10^{-04}$	$7.93 x10^{-03}$	$3.32x10^{-02}$	$6.32x10^{-03}$	$3.69x10^{-02}$	$2.19 x10^{-02}$	$9.32x10^{-03}$
F8	Average	$-4.99x10^{24}$	$-5.05x10^{07}$	$-2.52 x10^{03}$	$-2.65x10^{3}$	$-1.41 x10^{03}$	$-2.02x10^{03}$	$-2.32 x10^{03}$	$-1.16x10^{02}$	$-1.03 x10^{26}$
	Std	$2.09x10^{25}$	$1.51 x10^{08}$	$3.82 x10^{02}$	$3.65 x10^{2}$	$2.84 x10^{02}$	$1.78 x10^{2}$	$4.85x10^{2}$	$6.55x10^{-01}$	$1.60x10^{26}$
F9	Average	0	0	0	$1.75 x10^{01}$	$1.62 x10^{01}$	$6.78x10^{0}$	$2.22x10^{01}$	$4.91x10^{01}$	$3.63x10^{01}$
	Std	0	0	0	$1.13 x10^{01}$	$1.36 x10^{01}$	$1.04x10^{01}$	$1.09x10^{01}$	$8.08x10^{0}$	$5.02x10^{0}$
F10	Average	$8.88x10^{-16}$	$8.88x10^{-16}$	$4.04 x10^{-11}$	$8.02 x10^{-01}$	$5.24 x10^{0}$	$2.73 x10^{-01}$	$1.70x10^{0}$	$2.29x10^{0}$	$2.13x10^{-01}$
	Std	0	0	$1.12 x10^{-10}$	$8.86 x10^{-01}$	$5.32 x10^{0}$	$1.39x10^{0}$	$1.59x10^{0}$	$1.27x10^{0}$	$1.43x10^{-01}$
F11	Average	0	0	0	$2.37 x10^{-01}$	$1.10 x10^{2}$	$2.66x10^{-01}$	$1.56x10^{-01}$	$2.06x10^{-01}$	$5.26x10^{-01}$
	Std	0	0	0	$1.43 x10^{-01}$	$3.89 x10^{01}$	$2.04 x10^{-01}$	$7.27 x10^{-02}$	$1.77x10^{-01}$	$1.17x10^{-01}$
F12	Average	$1.51x10^{-02a}$	$7.21x10^{-02}$	$2.14 x10^{-01}$	$9.52 x10^{-01}$	$2.69 x10^{06}$	$3.03x10^{-01}$	$5.95x10^{0}$	$3.02x10^{-01}$	$1.74x10^{-01}$
	Std	$8.36x10^{-03}$	$3.36 x10^{-02}$	$8.69x10^{-02}$	$1.47 x10^{0}$	$8.55 x10^{06}$	$7.83 x10^{-01}$	$2.86x10^{0}$	$1.46x10^{-01}$	$2.39x10^{-01}$
F13	Average	$6.96x10^{-02}$	$2.92 x10^{-01}$	$1.07 x10^{-02}$	$2.19 x10^{-03}$	$1.93 x10^{07}$	$4.16x10^{-01}$	$5.67x10^{-03}$	$8.51x10^{-01}$	$6.98x10^{-02}$
	Std	$2.49x10^{-02}$	$1.61x10^{-01}$	$6.39 x10^{-03}$	$4.39 x10^{-03}$	$4.21 x10^{07}$	$8.72x10^{-02}$	$1.03x10^{-02}$	$2.18x10^{-01}$	$5.29x10^{-02}$
F14	Average	$1.09x10^{0}$	$1.34 x10^{0}$	$3.02 x10^{0}$	$1.19 x10^{0}$	$1.59 x10^{01}$	$1.83x10^{0}$	$4.92x10^{0}$	$12.67x10^{0}$	$1.04x10^{0}$
	Std	$3.62x10^{-01}$	$4.97 x10^{-01}$	$1.86 x10^{0}$	$4.73 x10^{-01}$	$7.50 x10^{01}$	$8.74x10^{-01}$	$3.93x10^{0}$	$1.37x10^{-04}$	$1.31x10^{-01}$
F15	Average	$3.45x10^{-04}$	$3.72x10^{-04}$	$3.58 x10^{-04}$	$3.51 x10^{-03}$	$2.97 x10^{-03}$	$1.08x10^{-03}$	$3.18x10^{-03}$	$7.58x10^{-03}$	$1.21x10^{-03}$
	Std	$2.51x10^{-05}$	$1.26x10^{-04}$	$2.77 x10^{-05}$	$6.63 x10^{-03}$	$1.20 x10^{-02}$	$4.44x10^{-04}$	$4.62x10^{-03}$	$6.51x10^{-03}$	$9.57x10^{-05}$
F16	Average	$-1.00x10^{0}$	$-1.031 x10^{0}$	$-1.03 x10^{0}$	$-1.031 x10^{0}$	$-1.031 x10^{0}$	$-1.031 x10^{0}$	$-1.03x10^{0}$	$-7.53x10^{-01}$	$-1.031 x10^{0}$
	Std	$1.92x10^{-03}$	$6.04 x10^{-05}$	$4.66 x10^{-03}$	$2.80 x10^{-14}$	$3.89 x10^{-10}$	$1.34x10^{-04}$	$3.18x10^{-13}$	$2.87x10^{-01}$	$1.04x10^{-06}$
F17	Average	$4.03x10^{-01}$	$3.98 x10^{-01}$	$4.00 x10^{-01}$	$3.97 x10^{-01}$	$4.53 x10^{-01}$	$4.04 x10^{-01}$	$3.98x10^{-1}$	$7.13x10^{-01}$	$3.98 x10^{-01}$
	Std	$5.76x10^{-03}$	$2.24x10^{-04}$	$4.95 x10^{-03}$	$4.30 x10^{-14}$	$2.98 x10^{-04}$	$7.64 x10^{-03}$	$2.71x10^{-13}$	$1.79 x10^{-01}$	$7.93x10^{-05}$
F18	Average	$3.00x10^{0}$	$3 x10^{0}$	$4.47 x10^{0}$	$3 x10^{0}$	$3 x10^{0}$	$3 x10^{0}$	$3 x10^{0}$	$8.26x10^{01}$	$3 x10^{0}$
	Std	$4.81x10^{-04}$	$3.43x10^{-05}$	$1.46 x10^{0}$	$1.22 x10^{-13}$	$9.37 x10^{-04}$	$6.45x10^{-04}$	$2.31x10^{-12}$	$2.49x10^{01}$	$1.82x10^{-05}$
F19	Average	$-3.86x10^{0}$	$-3.85 x10^{0}$	$-3.85 x10^{0}$	$-3.86 x10^{0}$	$-3.86 x10^{0}$	$-3.85 x10^{0}$	$-3.86x10^{0}$	$-2.85x10^{0}$	$-3.86 x10^{0}$
	Std	$3.71x10^{-03}$	$2.74x10^{-03}$	$1.22 x10^{-02}$	$6.81 x10^{-12}$	$4.54 x10^{-03}$	$6.68x10^{-03}$	$9.07x10^{-05}$	$7.64x10^{-01}$	$2.27x10^{-09}$
F20	Average	$-3.18x10^{0}$	$-3.08x10^{0}$	$-3.13 x10^{0}$	$-3.22 x10^{0}$	$-3.25 x10^{0}$	$-2.95x10^{0}$	$-3.27x10^{0}$	$-5.73x10^{-01}$	$-3.32 x10^{0}$
	Std	$5.61x10^{-02}$	$8.46x10^{-02}$	$1.02 x10^{-02}$	$5.66 x10^{-02}$	$9.09 x10^{-02}$	$1.93x10^{-01}$	$6.16x10^{-02}$	$5.39x10^{-01}$	$1.08x10^{-02}$
F21	Average	$-5.95x10^{0}$	$-4.89x10^{0}$	$-5.18 x10^{0}$	$-8.06 x10^{0}$	$-5.38 x10^{0}$	$-2.46x10^{0}$	$-6.11x10^{0}$	$-2.83x10^{0}$	$-9.62x10^{0}$
	Std	$1.22x10^{-01}$	$2.09 x10^{-01}$	$9.01 x10^{-01}$	$3.04 x10^{0}$	$3.45x10^{0}$	$1.93x10^{0}$	$2.56x10^{0}$	$8.11x10^{-01}$	1.35x10
F22	Average	$-6.13x10^{0}$	$-4.88x10^{0}$	$-5.20 x10^{0}$	$-9.29 x10^{0}$	$-6.42 x10^{0}$	$-3.55x10^{0}$	$-5.48x10^{0}$	$-2.70x10^{0}$	$-10.38 x10^{0}$
	Std	$1.33 x10^{-01}$	$8.02 x10^{-02}$	$8.74 x10^{-01}$	$2.54 x10^{0}$	$3.58 x10^{0}$	$1.87x10^{0}$	$2.86x10^{0}$	$9.03x10^{-01}$	$1.22x10^{-01}$
F23	Average	$-6.92 x10^{0}$	$-4.89 x10^{0}$	$-5.25 x10^{0}$	$-7.90 x10^{0}$	$-4.89 x10^{0}$	$-4.16 x10^{0}$	$-5.08x10^{0}$	$-2.76x10^{0}$	$-10.54 x10^{0}$
	Std	$1.91 x10^{-01}$	$1.05x10^{0}$	$9.14 x10^{-01}$	$3.52 x10^{0}$	$3.49 x10^{0}$	$1.31x10^{0}$	$3.40x10^{0}$	$7.27x10^{-01}$	$1.96x10^{-05}$


DG_1
PV
Boost Converter
Battery
Bidirectional DC-DC converter
Super Capacitor
Bidirectional DC-DC converter
RLC Filter
Droop Control
Voltage-Current Controller
DG_2
Fuel Cell
Boost Converter
Battery
Bidirectional DC-DC converter
Super Capacitor
Bidirectional DC-DC converter
RLC Filter
Droop Control
Voltage-Current Controller
Load

Results of the Applied nine Optimization Techniques

	SSA	PSO	SCA	ALO	DA	ABC	SSIA-PSO	HGSO	HGSO-SCA
Objective function	10.25 $x10^6$	12.66 $x10^6$	13.76 $x10^6$	11.22$x10^6$	11.25$x10^6$	18.460$x10^6$	6.08 $x10^6$	5.8613$x10^6$	5.4376$x10^6$
Kp1	0.691433	0.557908	0.622222	0.532215	0.253903	0.641502	0.312331	0.45173	0.286283
Ki1	311.4964	475.0824	242.9766	521.9489	382.4229	530.0400	353.2782	257.9713	386.5565
Kp2	0.548548	0.513765	0.288695	0.537495	0.386742	0.470766	0.550147	0.468047	0.26959
Ki2	543.6527	565.1678	550.6742	537.8442	438.6973	349.2290	351.9411	387.772	322.6721
Kp3	11.27808	13.09909	7.515493	14.58615	9.276742	12.22560	15.30740	13.99621	10.84628
Ki3	13879.68	12410.52	14587.14	6500.108	14416.69	6358.140	12837.96	10480.54	12007.58
Kp4	10.25541	13.05646	6.854758	7.378885	8.530060	9.003440	8.163614	5.413205	13.33705
Ki4	14414.39	11132.63	13968.29	10557.64	6300.102	13267.80	10772.97	11112.94	7483.837
nq	0.272247	0.225909	0.228627	0.367958	0.390588	0.266158	0.347973	0.315453	0.170722
mp	0.014868	0.009724	0.012441	0.014005	0.015810	0.015636	0.013713	0.010452	0.016344
Time Taken (min)	207.2686	219.1358	218.7167	212.2842	209.5110	224.4803	205.7367	296.0268	254.8236

Fuzzy Droop Control

There is a fundamental question, "Why use fuzzy logic in control systems?"

1) One needs to know about the model and the objective function formulated in precise terms when applying traditional control. In many cases, this makes it very hard to apply.
2) Fuzzy control logic relies on making use of human expertise and experience to design a controller.
3) In designing a controller, the fuzzy control rules, essentially the IF-THEN rules, can be better used.

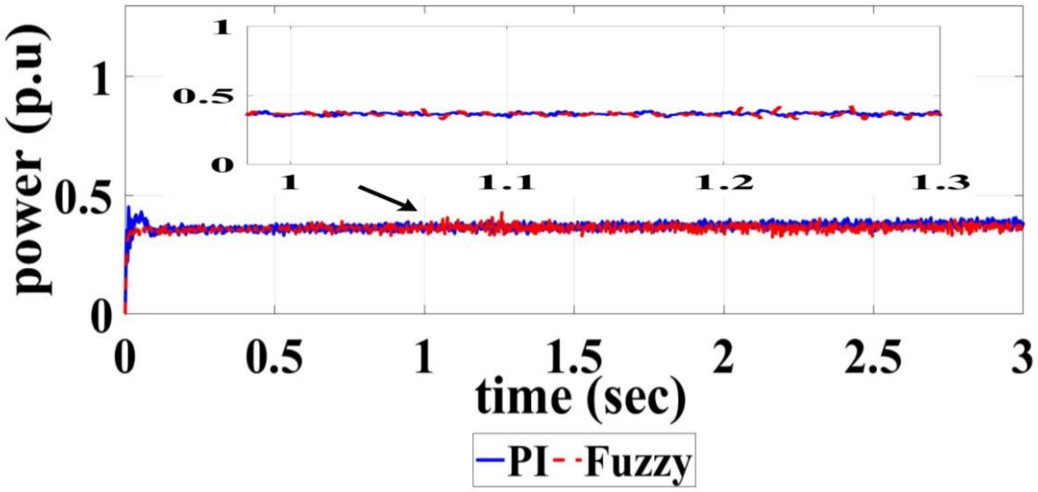
Parameters of Fuzzy Logic Control

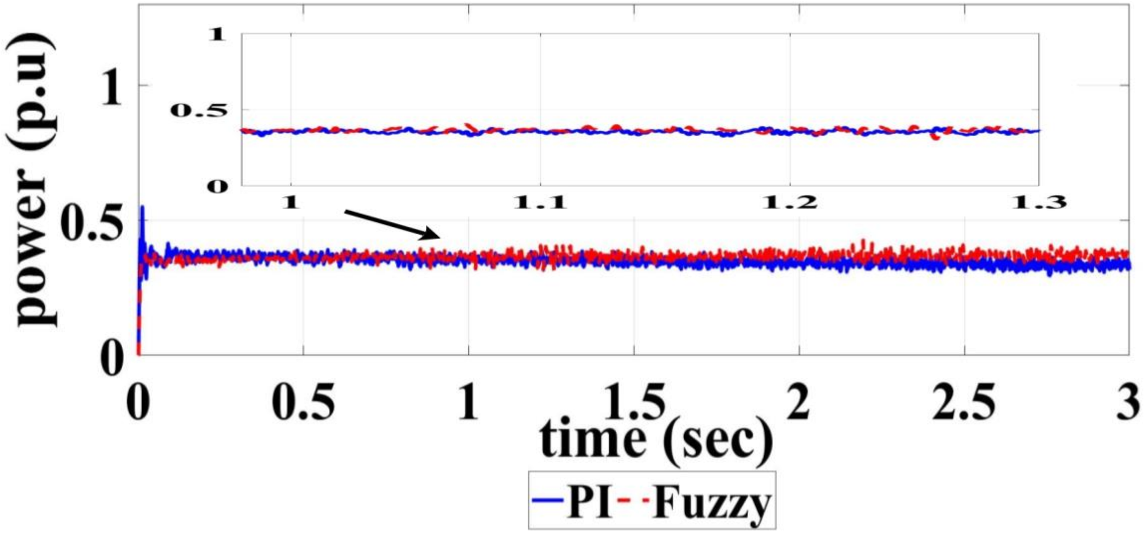
Objective function	3.7926×10^{04}
Z_{p1}	0.125
Z_{i1}	0.00000625
Z_{d1}	280
Z_{p2}	0.18734
Z_{i2}	0.00000598
Z_{d2}	297.23
Z_{p3}	0.008125
Z_{i3}	0.00002125
Z_{d3}	948700
Z_{p4}	0.00768
Z_{i4}	0.0000198
Z_{d4}	963000
N_q	0.1287952
M_p	0.0007904
Time Taken (min)	100.4829

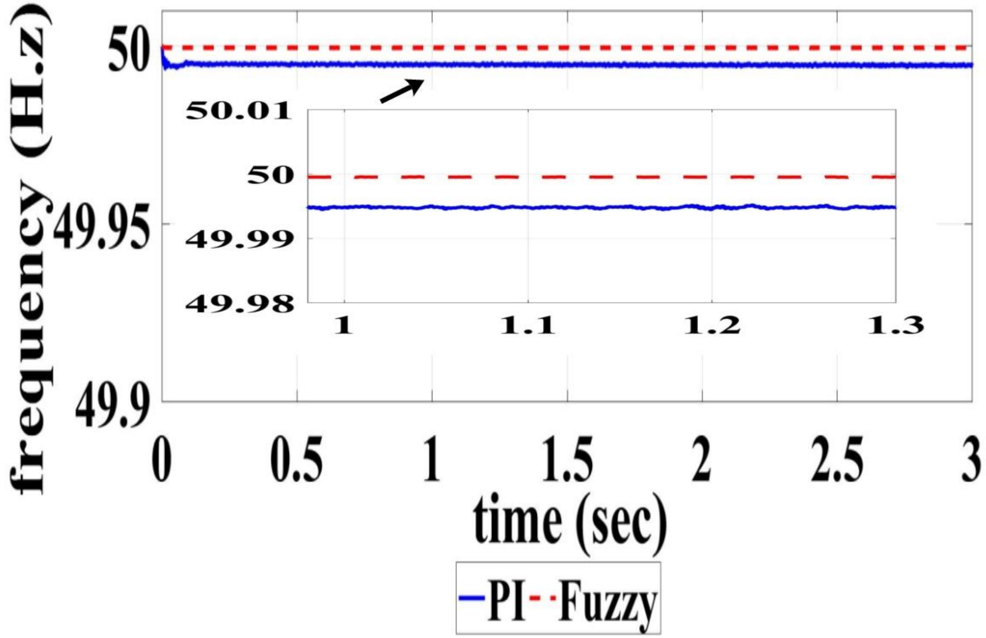
Simulation Results

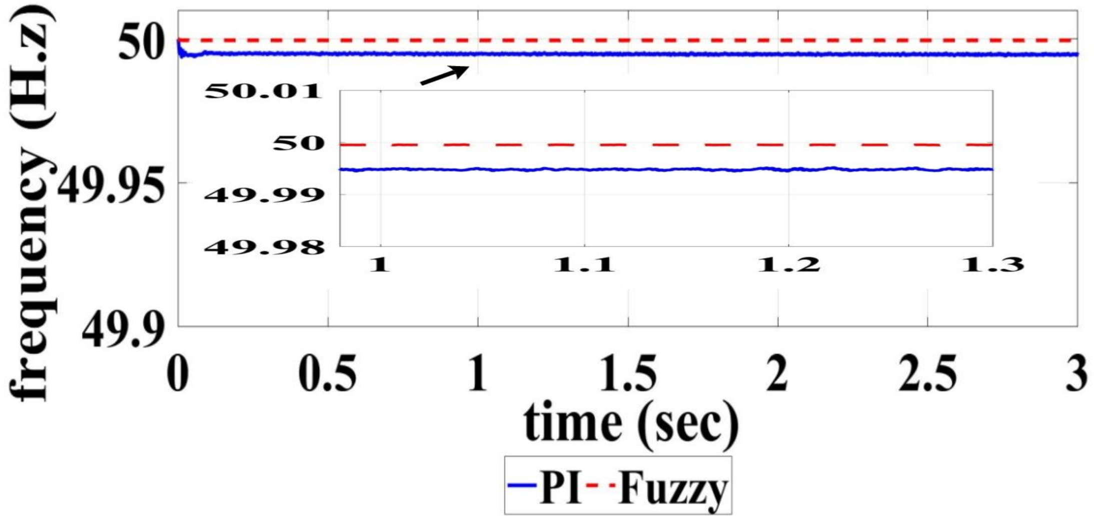
1) Islanding Mode with Fixed Cyclic Load Variations Scenario (IMFCLVS)
2) Islanding Mode with Unit Step Cyclic Load Variations Scenario (IMUSCLVS)
3) Islanding Mode with Continuous Cyclic Load Variations Scenario (IMCCLVS)
4) Islanding Mode with Ramp Load Variations Scenario (IMRLVS)
5) Islanding Mode with outage of full cell sources Scenario (IMOFCS)

Islanding Mode with Fixed Cyclic Load Variations Scenario (IMFCLVS)

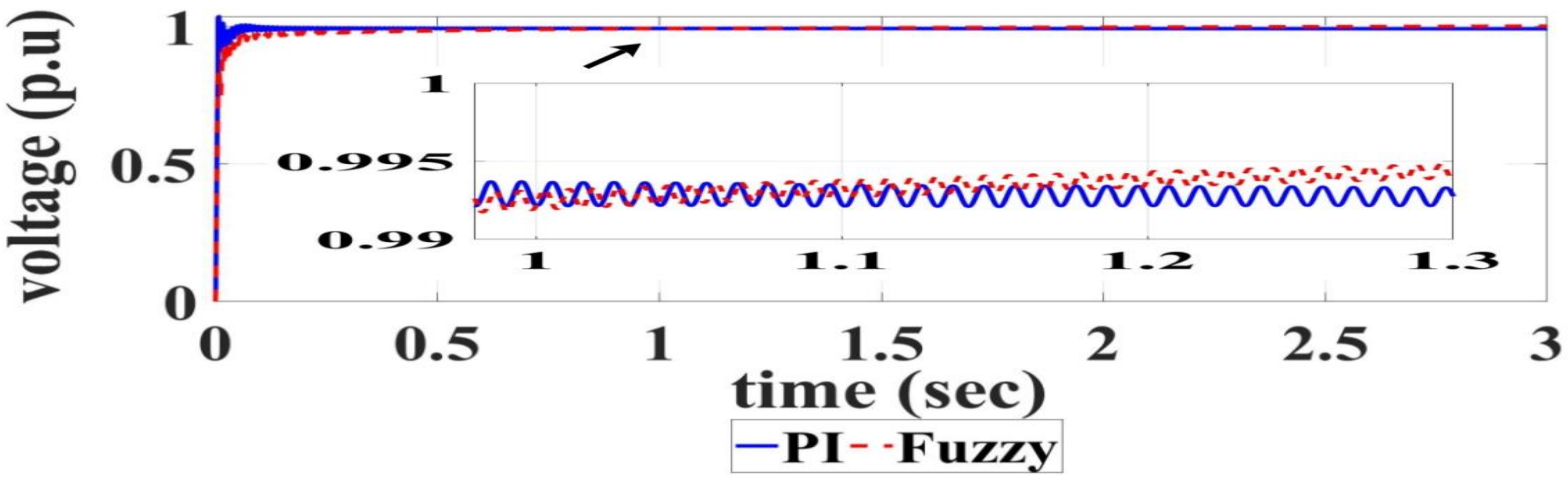


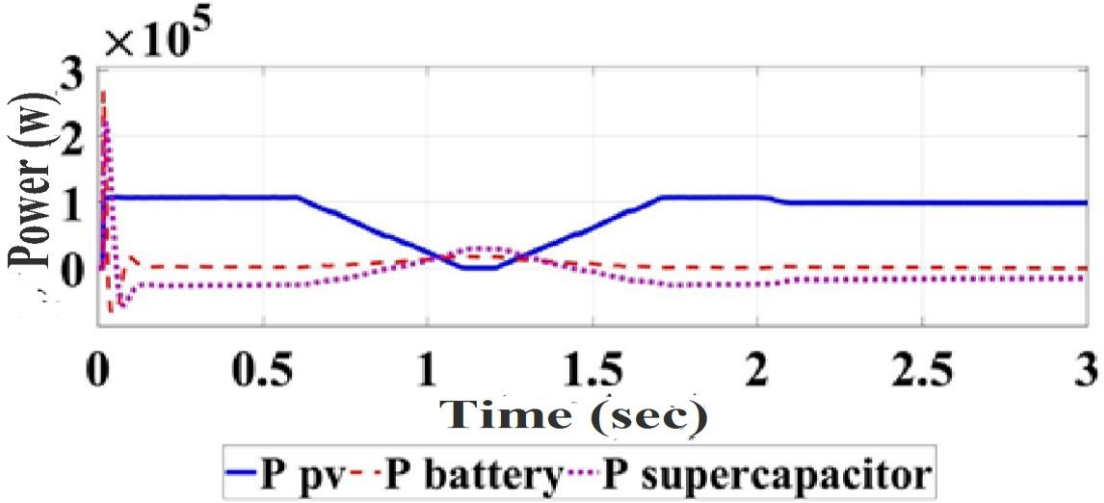




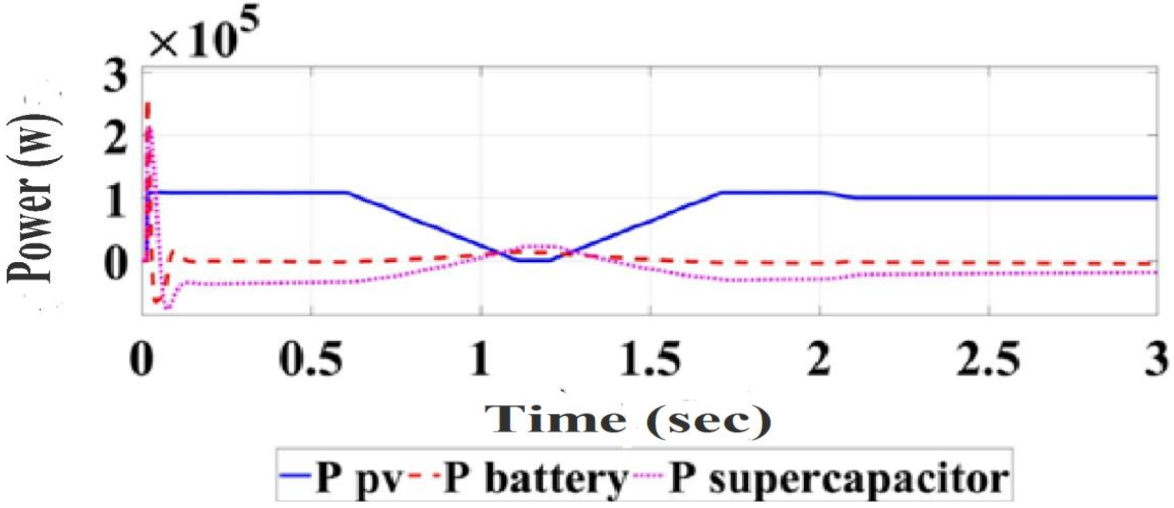


Islanding Mode with Fixed Cyclic Load Variations Scenario (IMFCLVS)



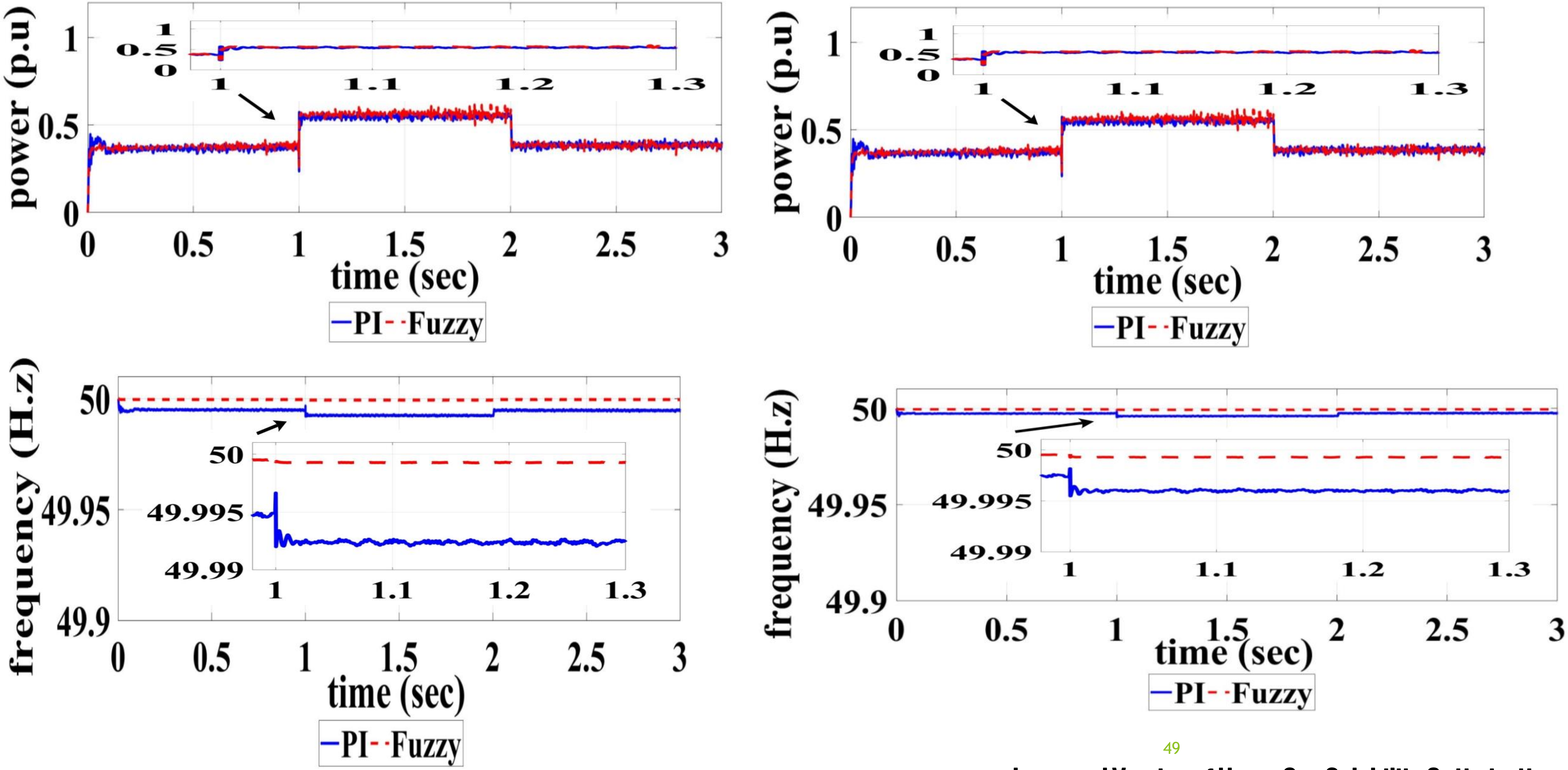


Powers of SPVASs, BSs, and SC in PI droop control

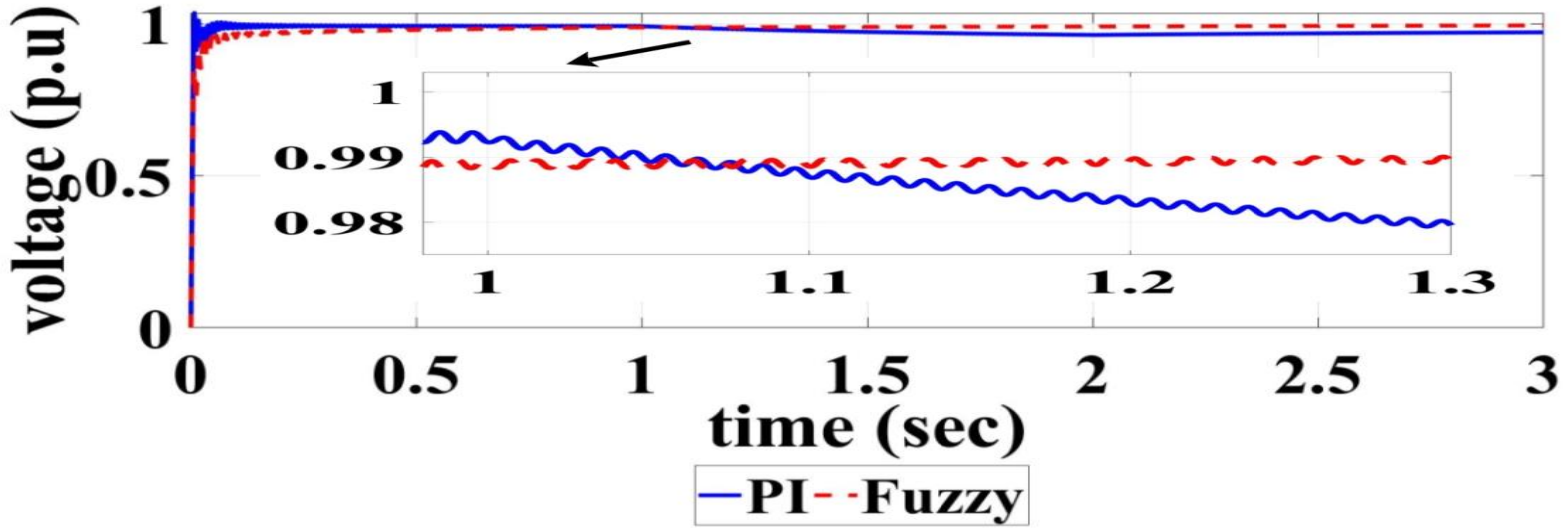


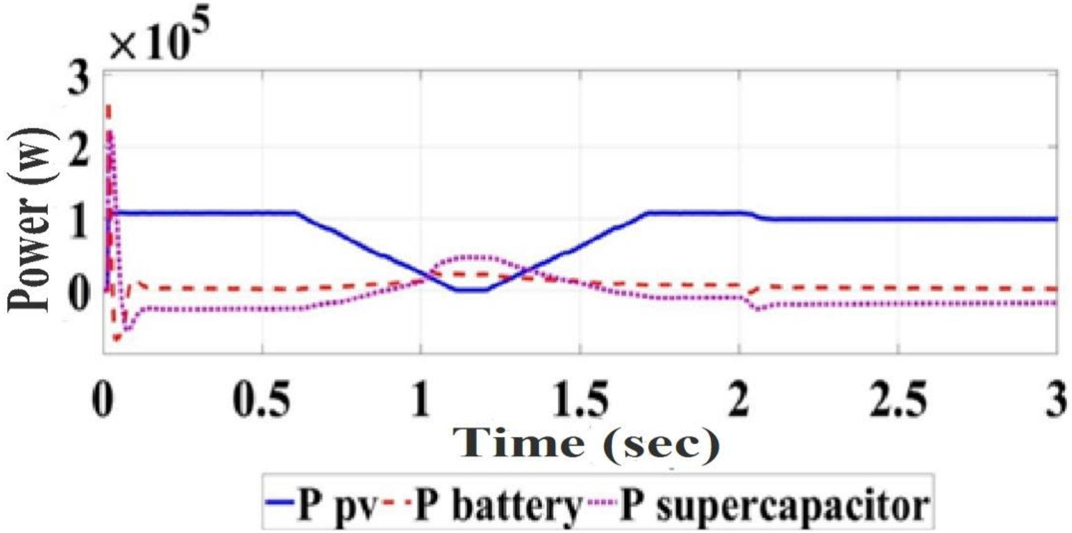
Powers of SPVASs, BSs, and SC in fuzzy droop control

Islanding Mode with Unit Step Cyclic Load Variations Scenario (IMUSCLVS)

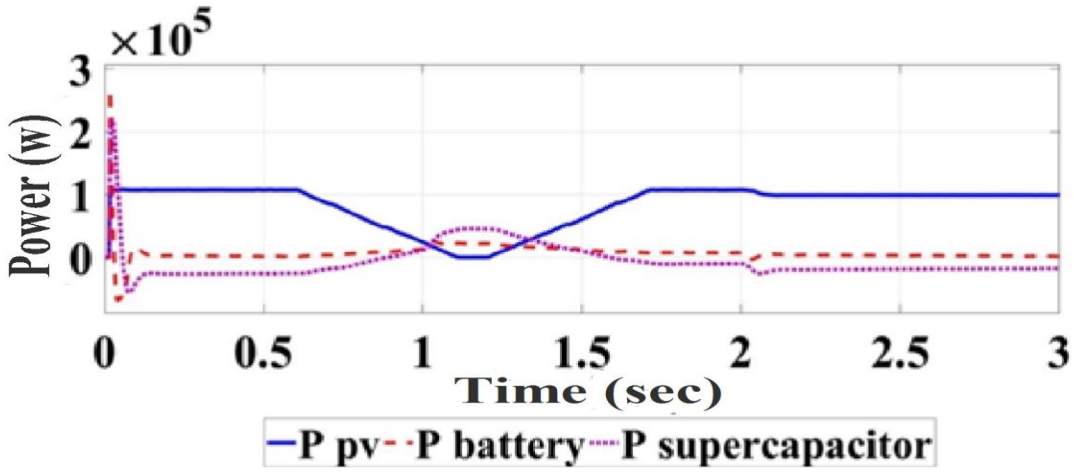


Islanding Mode with Unit Step Cyclic Load Variations Scenario (IMUSCLVS)



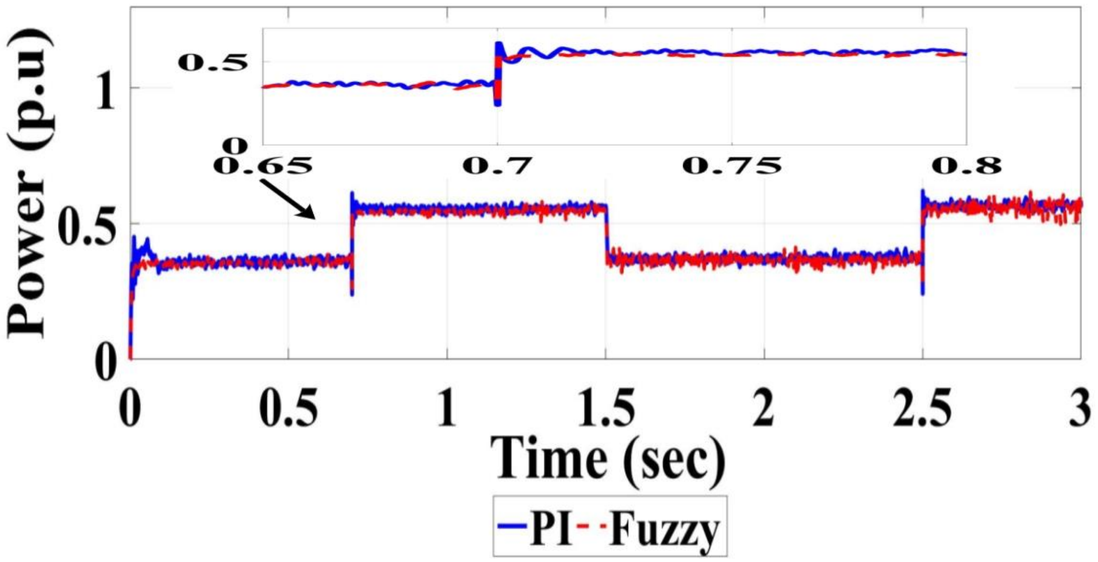


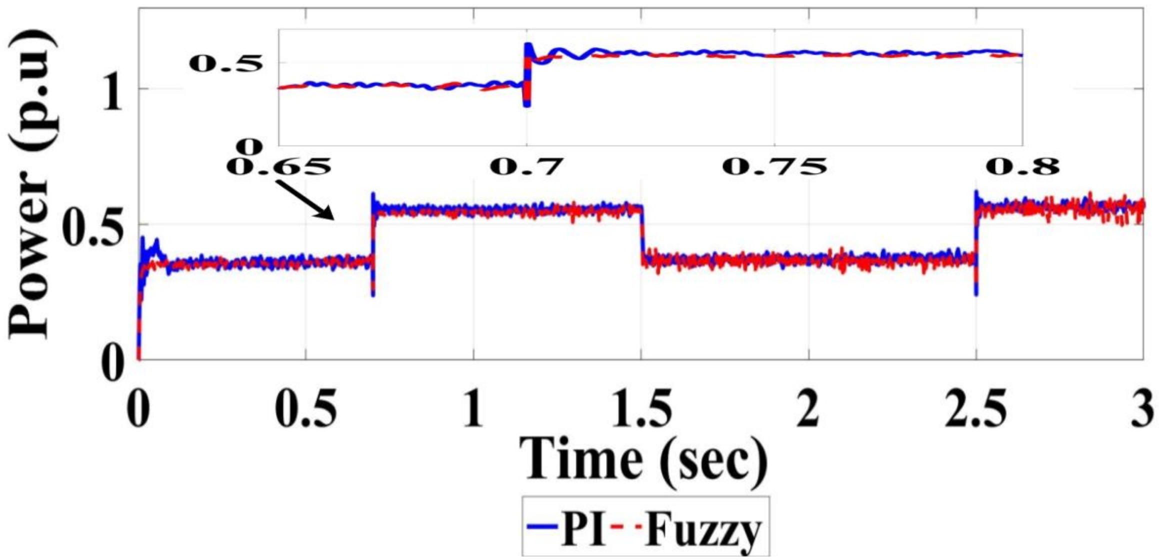
Powers of SPVASs, BSs, and SC in PI droop control

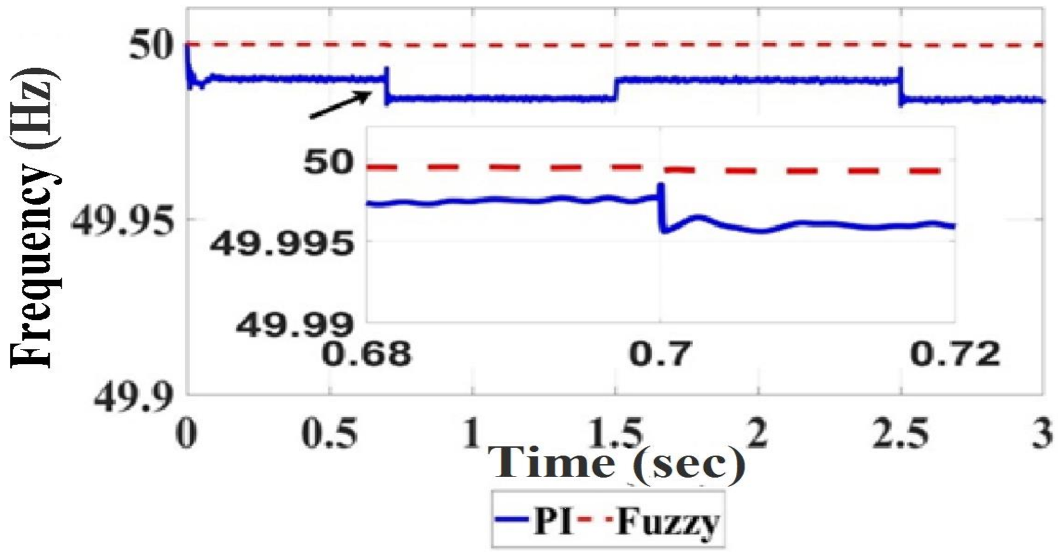


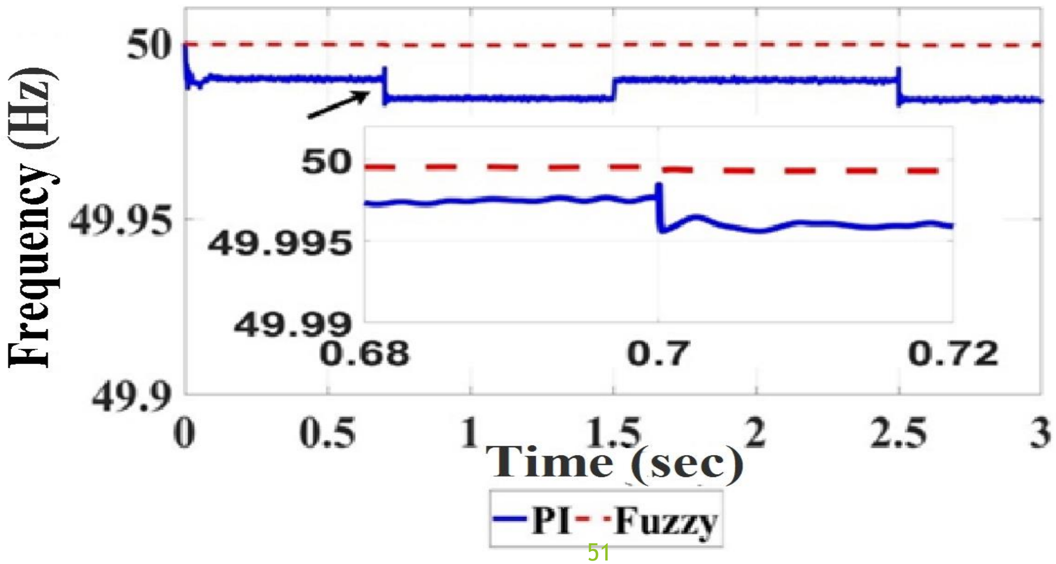
Powers of SPVASs, BSs, and SC in fuzzy droop control

Islanding Mode with Continuous Cyclic Load Variations Scenario (IMCCLVS)

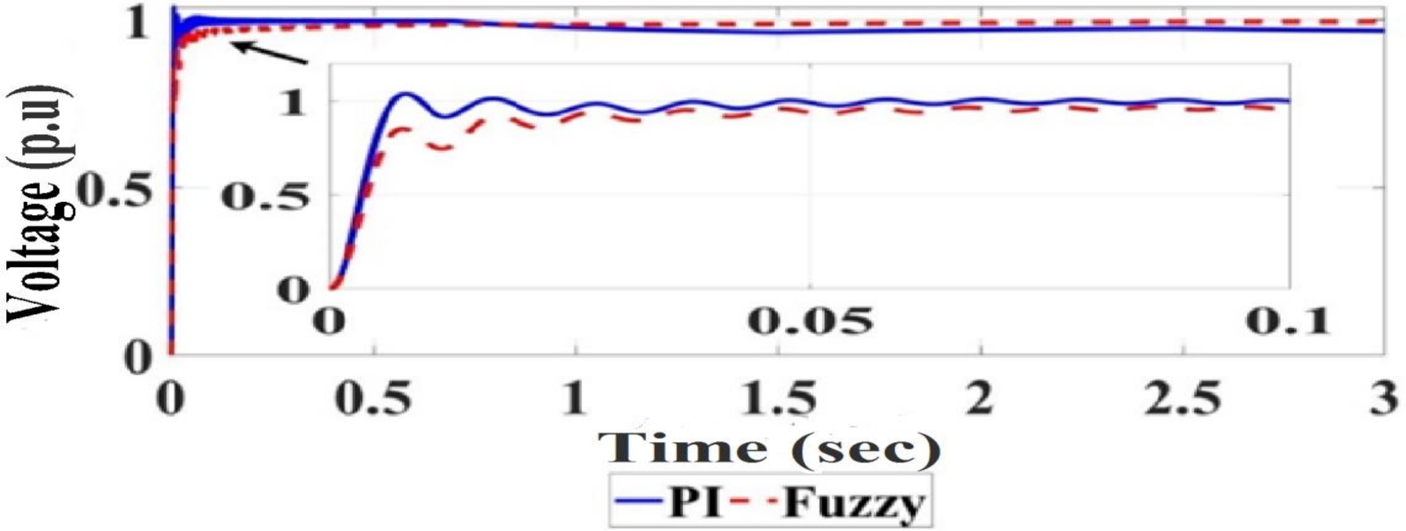


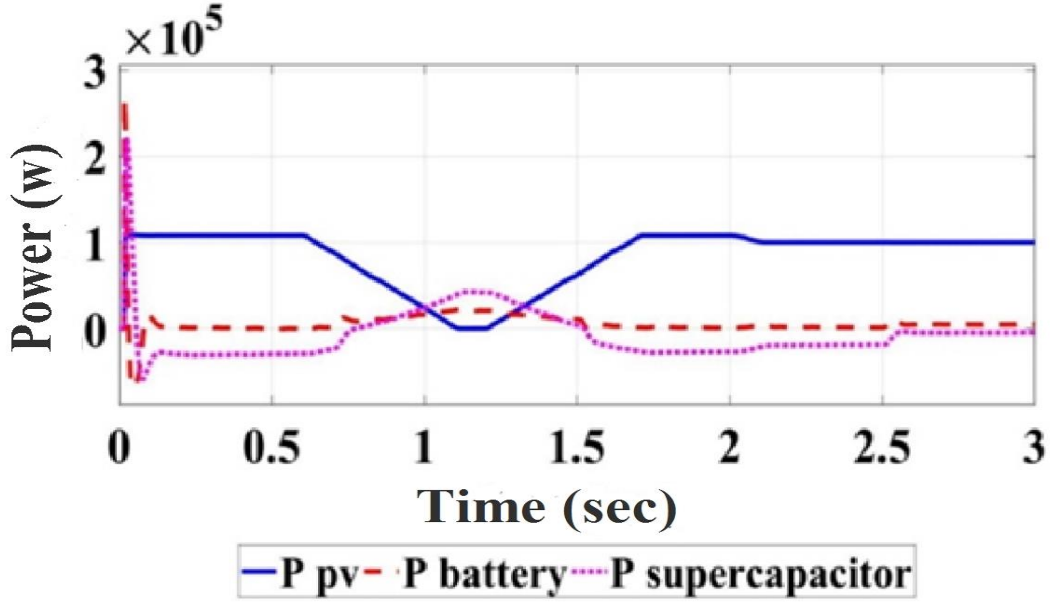


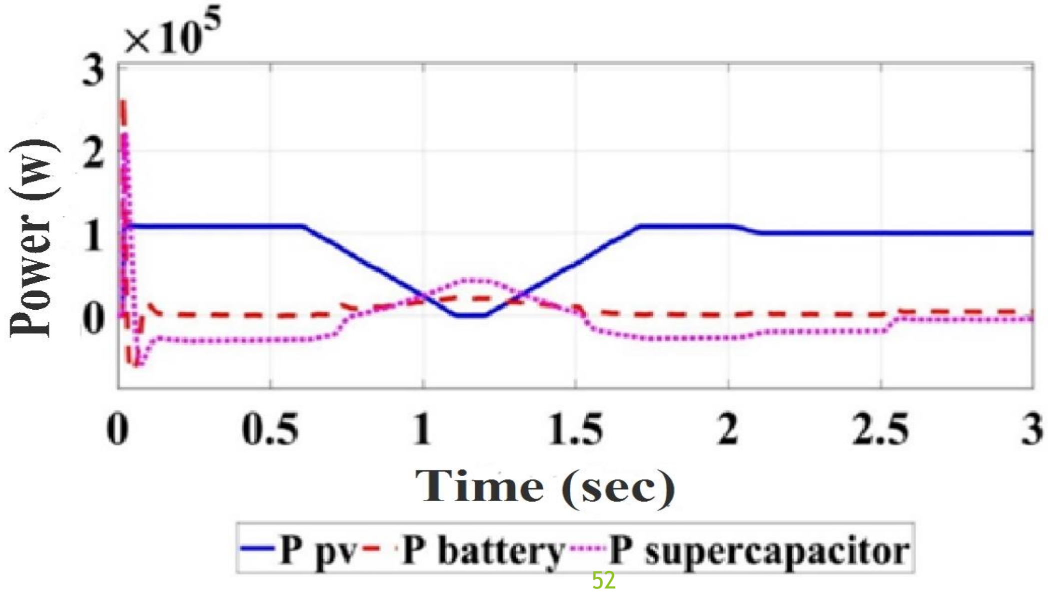




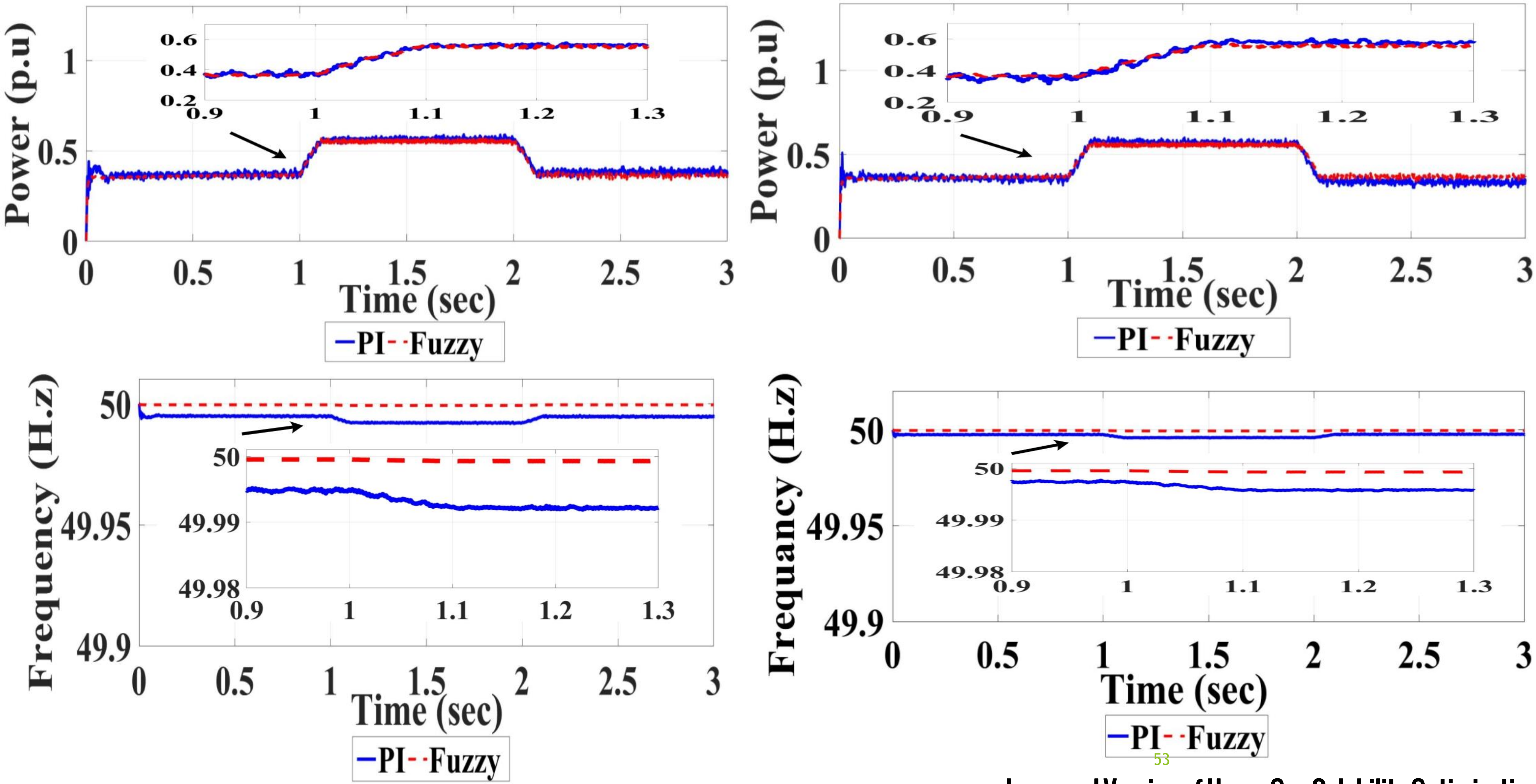
Islanding Mode with Continuous Cyclic Load Variations Scenario (IMCCLVS)



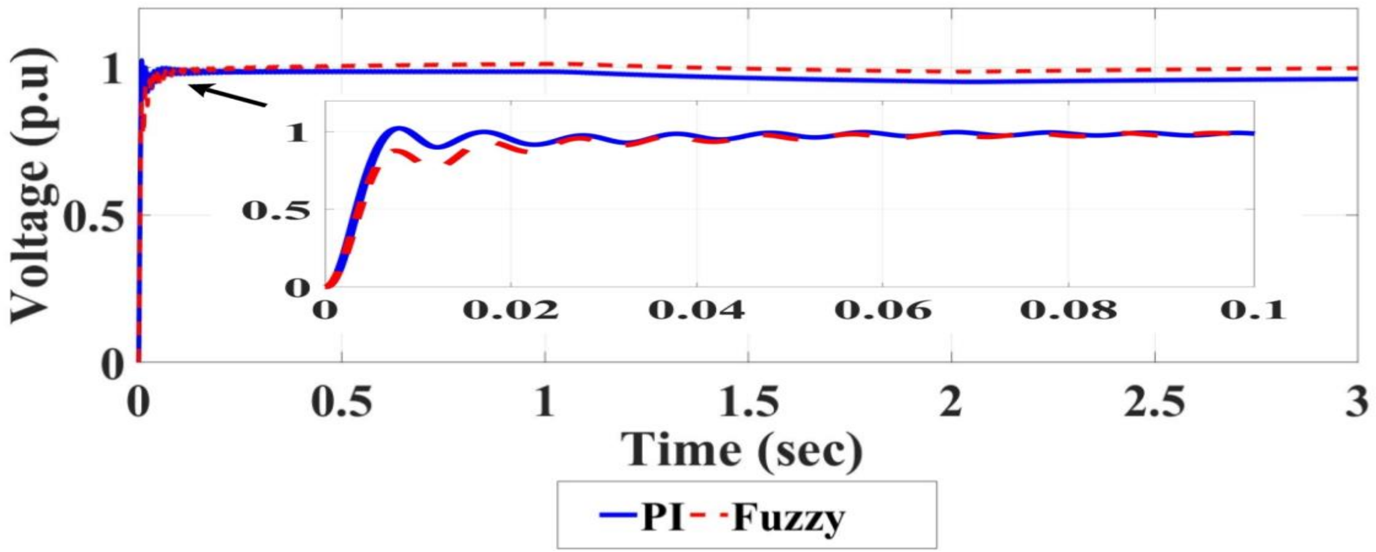


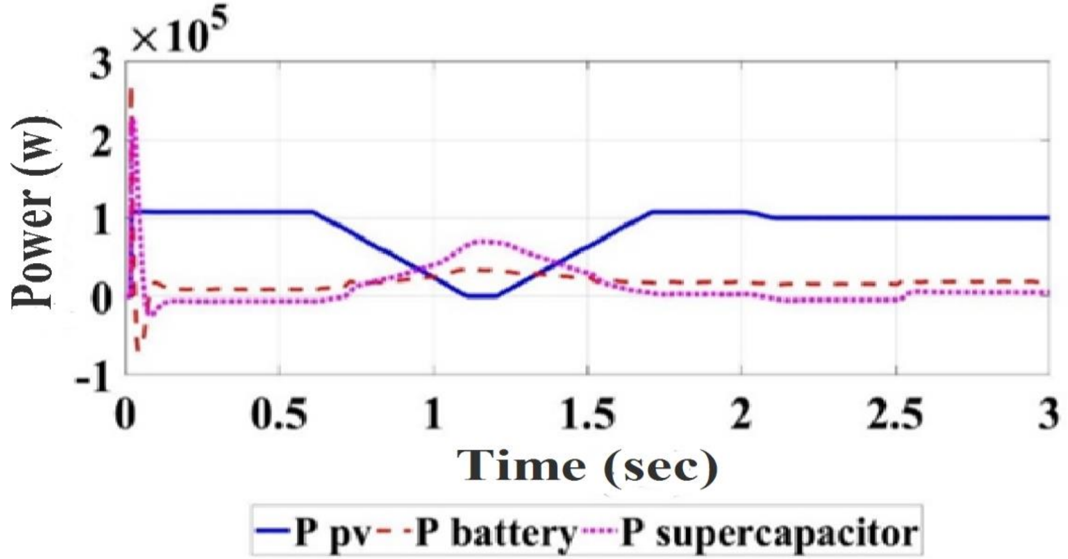


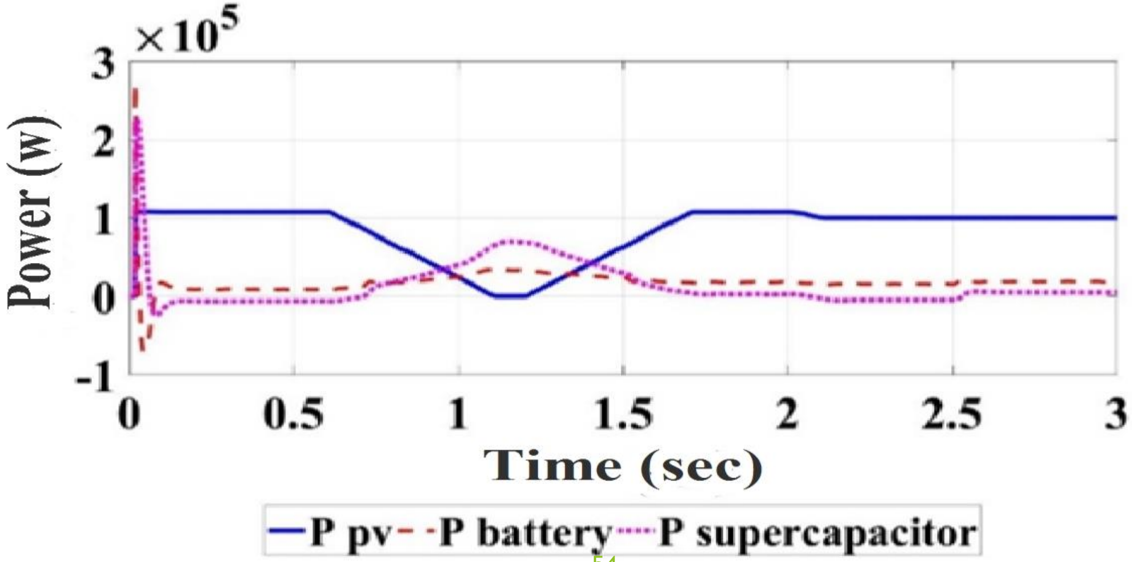
Islanding Mode with Ramp Load Variations Scenario (IMRLVS)



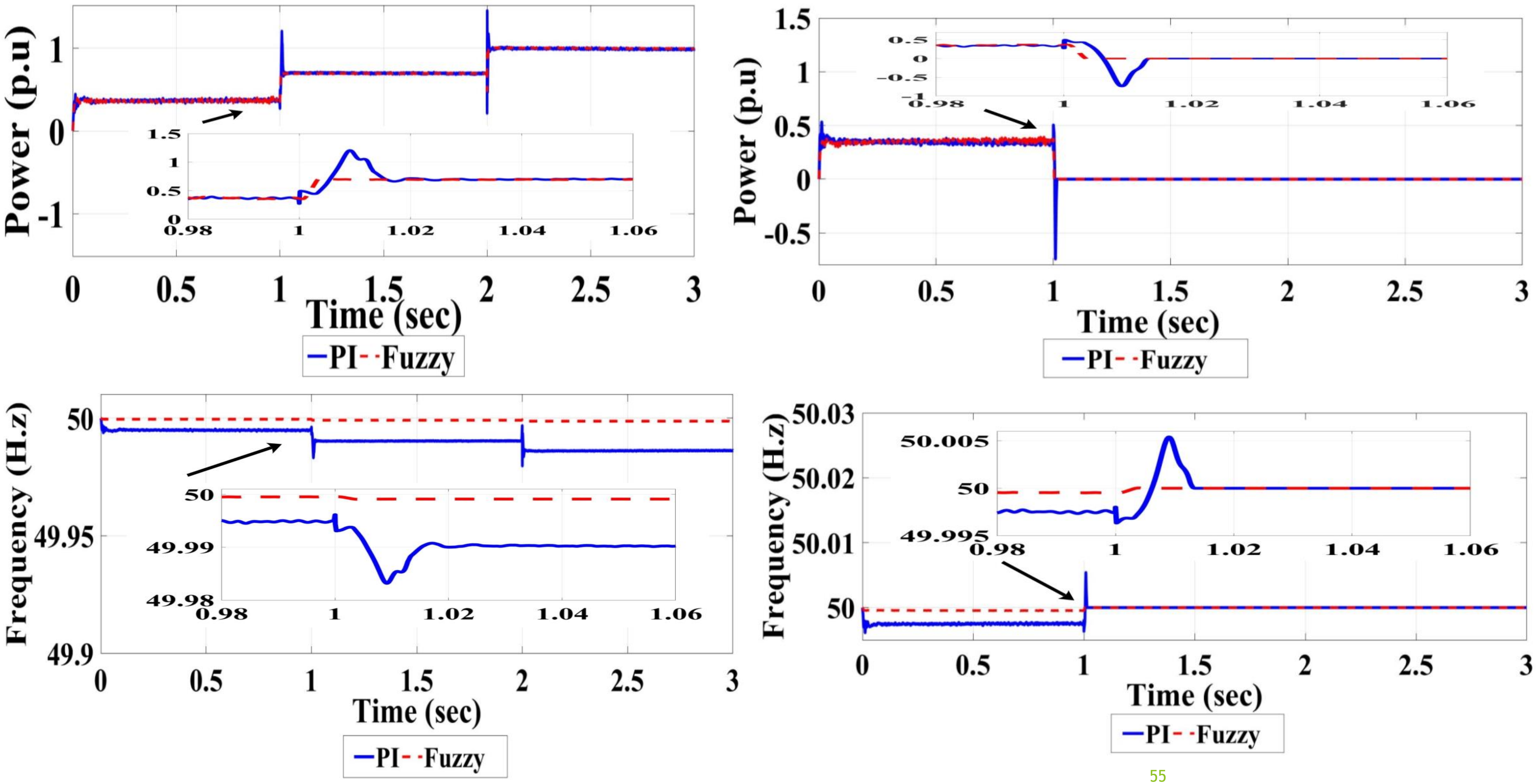
Islanding Mode with Ramp Load Variations Scenario (IMRLVS)



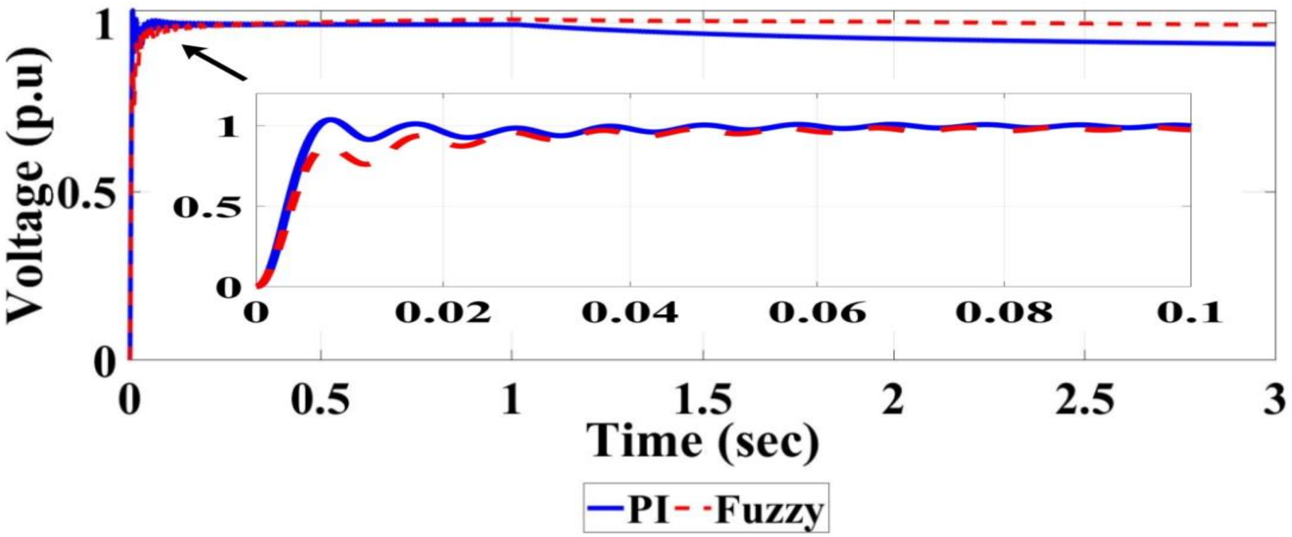


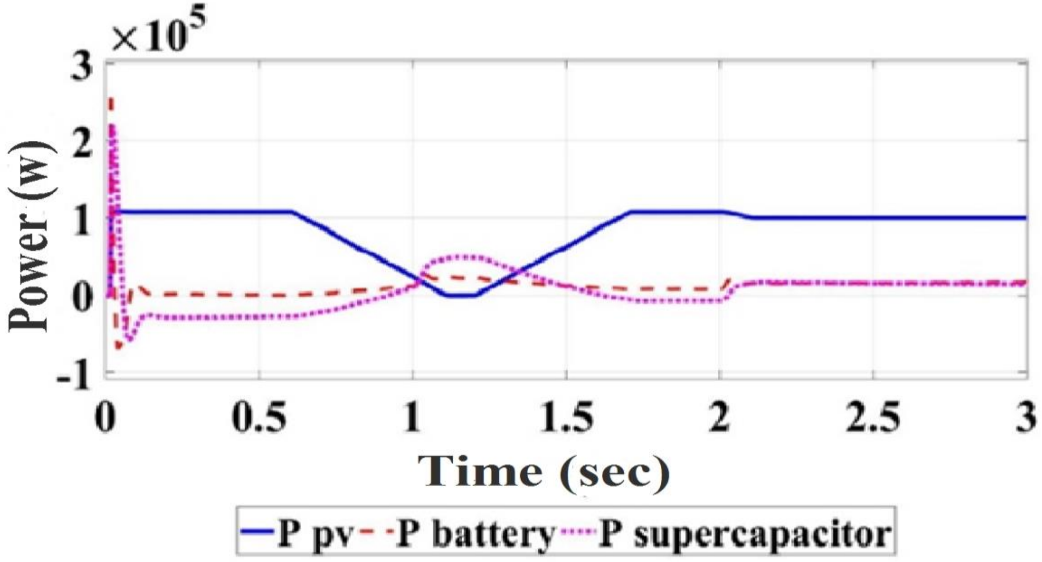


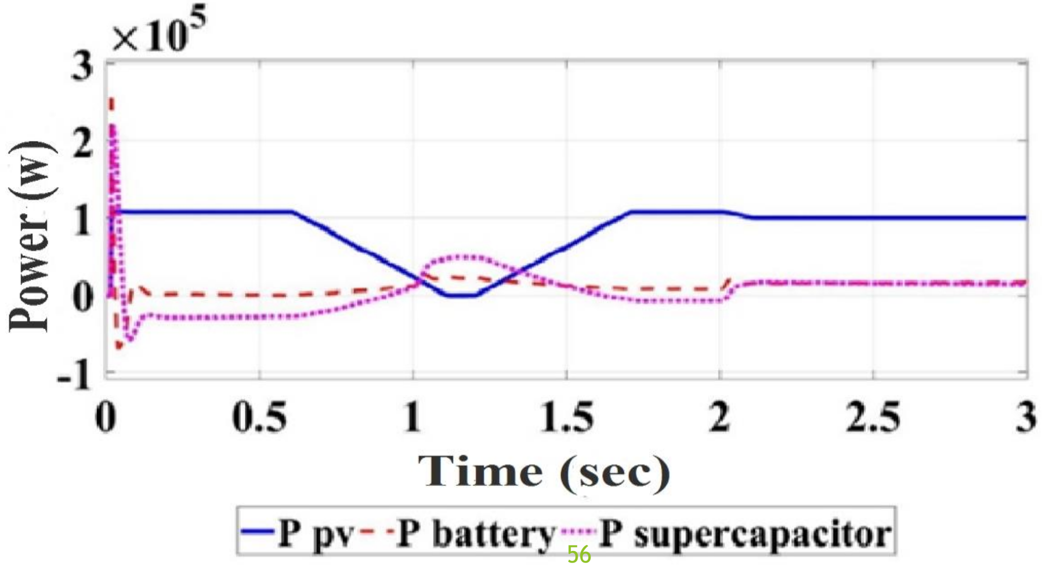
Islanding Mode with outage of full cell sources Scenario (IMOFCS)



Islanding Mode with outage of full cell sources Scenario (IMOFCS)



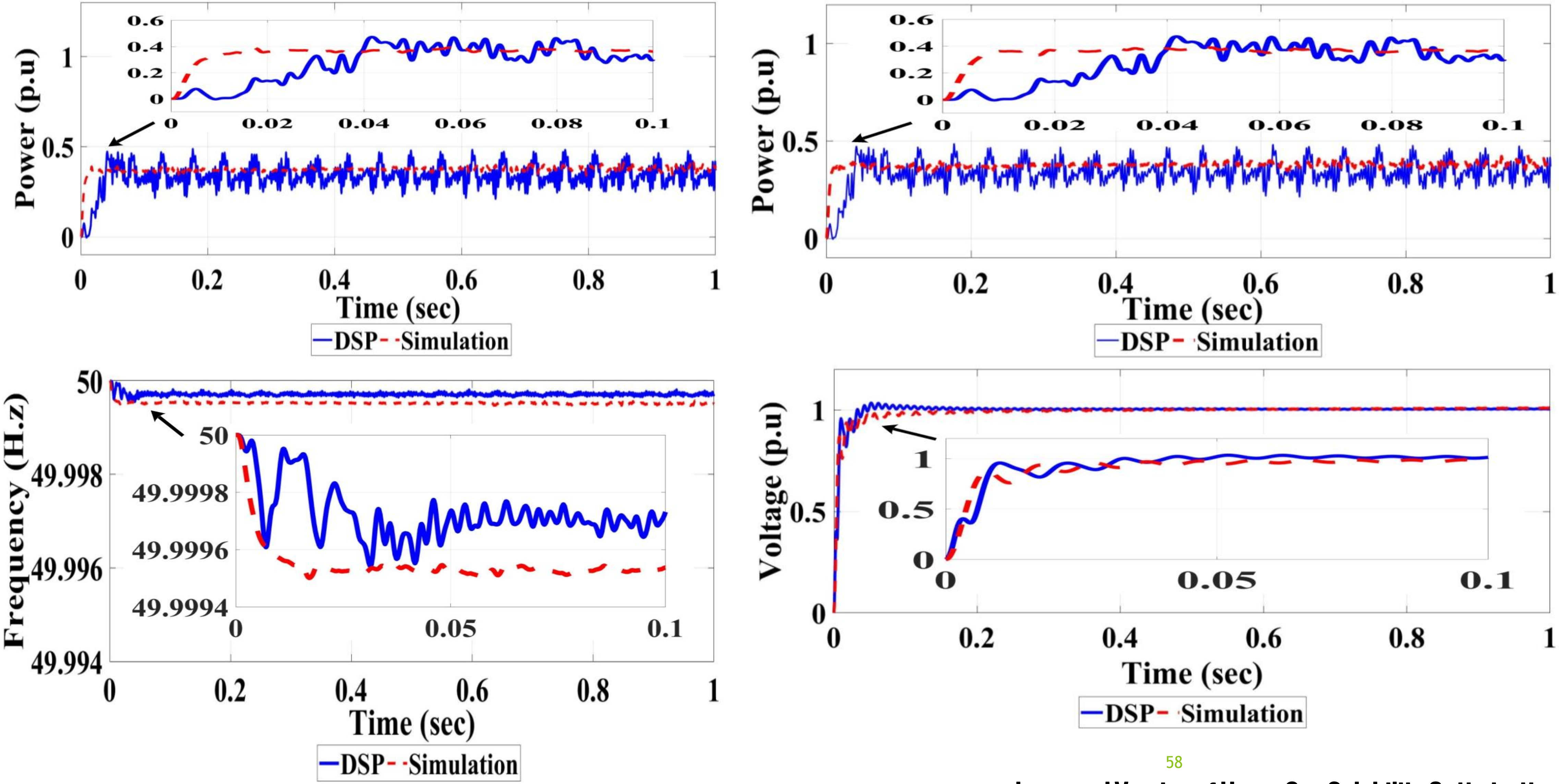




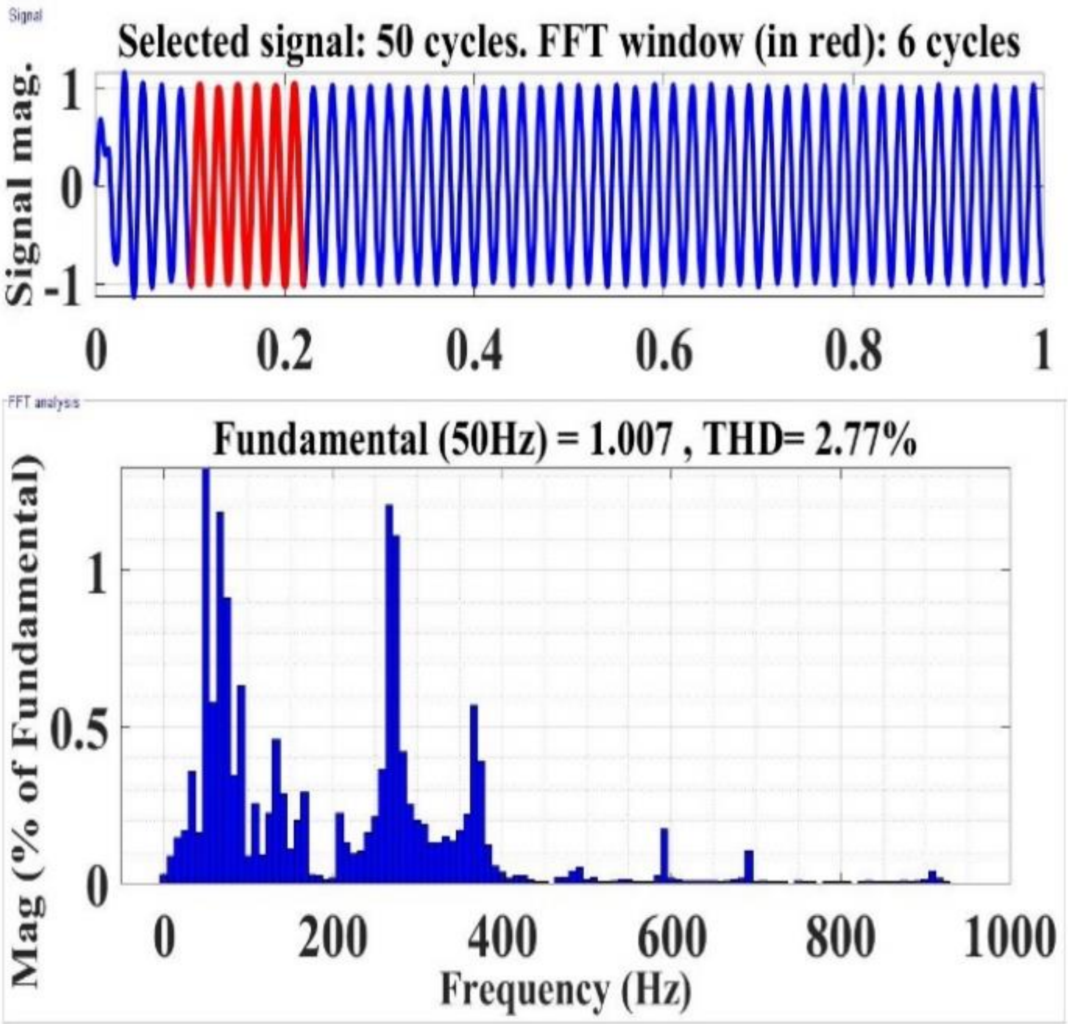
Experimental set-up and performance

1) Islanding Mode with Fixed Cyclic Load Variations Scenario (IMFCLVS)
2) Islanding Mode with Cyclic Load Variations Scenario (IMCLVS)

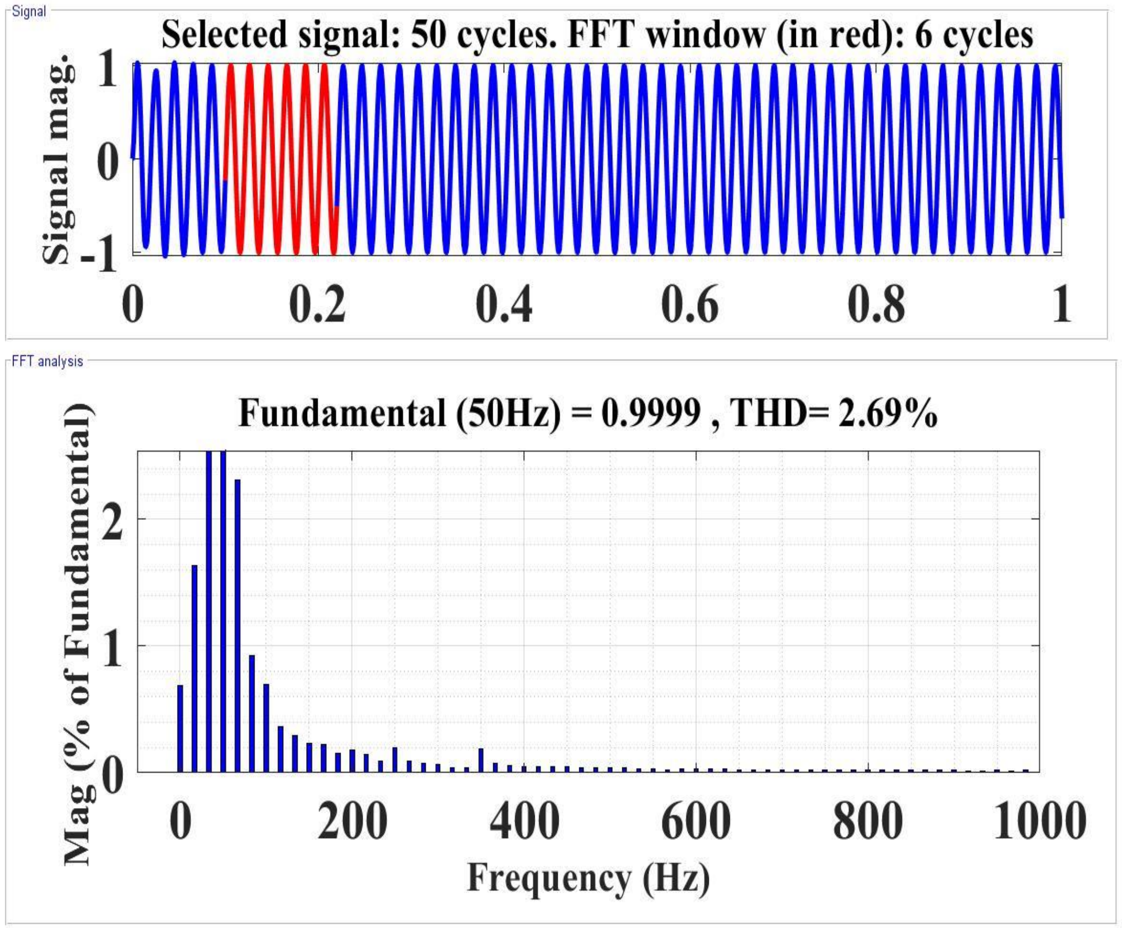
Islanding Mode with Fixed Cyclic Load Variations Scenario (IMFCLVS)



Islanding Mode with Fixed Cyclic Load Variations Scenario (IMFCLVS)

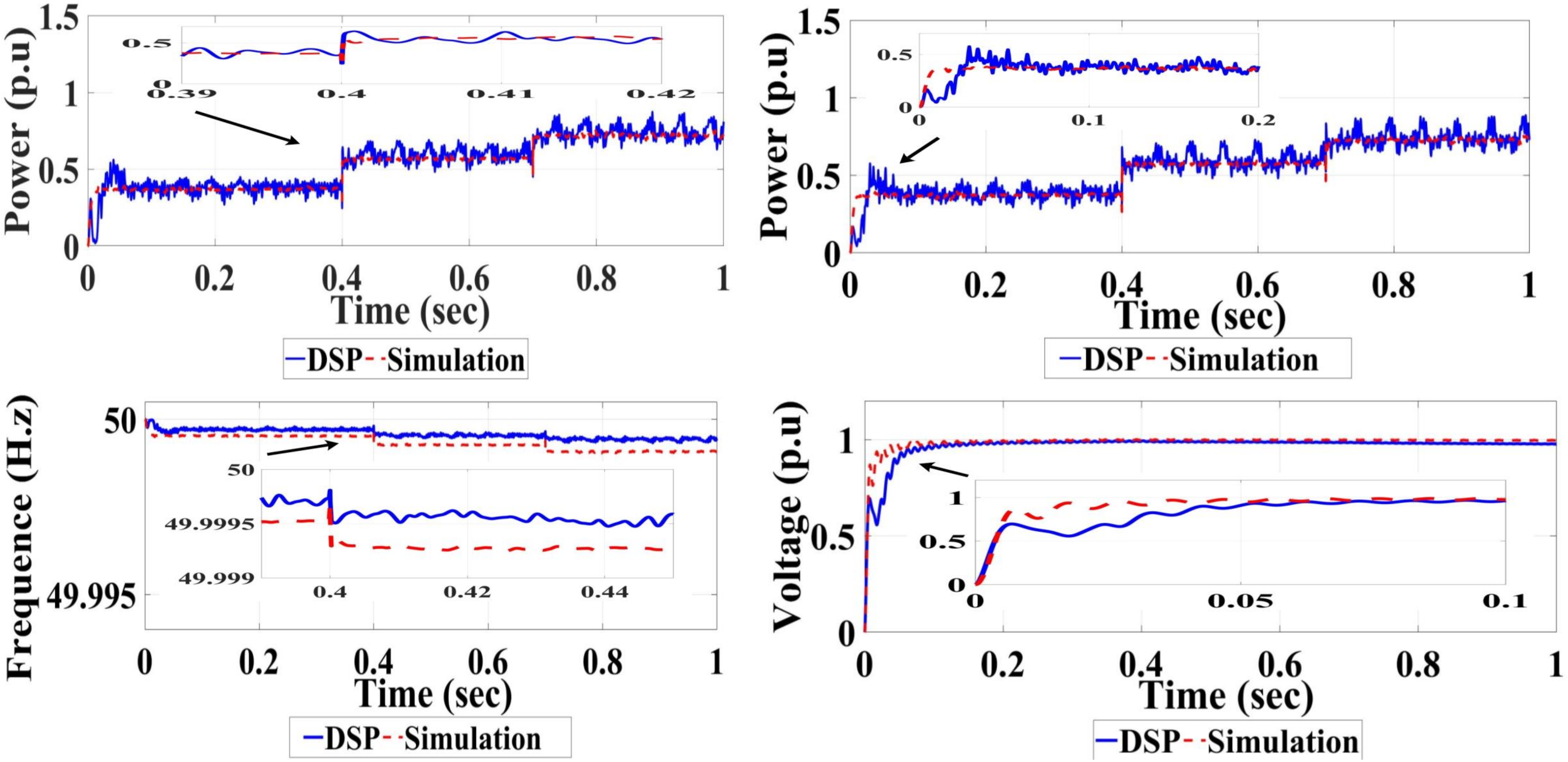


The FFT analysis in DSP of the proposed fuzzy droop controller in DSP



The FFT analysis in simulation of the proposed controller in simulation MATLAB

Islanding Mode with Cyclic Load Variations Scenario (IMCLVS)



Conclusion

1) A new version of the Salp Swarm Inspired Algorithm (SSIA) is hybrid with Particle Swarm Optimization (PSO) referential hybridization.

2) To demonstrate the ability of the proposed updated SSIA with seven different types of metaheuristic optimization techniques, such as single as well as hybrid algorithm between SSIA and PSO, a solid comparative study is performed.

3) The developed hybrid SSIA-PSO was proposed to solve one of the most common technical microgrid issues raised in the optimal design for the PI controller parameters and droop control parameters in order to maintain equal power sharing between different sources.

4) Using LAUNCHXL-F28379D, the real-time test bench is designed to check the theoretical results of the proposed optimization technique. In addition, to demonstrate the effectiveness of the proposed SSIA-PSOO, a detailed comparative review is carried out between the simulation and experimental results.

5) A new version of the Improved Version of Henry Gas Solubility Optimization (HGSO) is hybrid with Sine-cosine algorithm (SCA).

6) A solid comparative analysis was conducted to demonstrate the potential of the proposed modified HGSO with eight different types of metaheuristic optimization techniques.

7) To decide the optimal parameters of a decentralized control system based on two controller types, PI Droop Control (PIDC) and Fuzzy Droop Control (Fuzzy Droop Control), a new hybrid HGSO-SCA is used (FDC).

8) Using the Texas Instruments Launchpad TMS320F28379D, the implemented FDC control strategies based on HGSO-SCA, are tested experimentally in a real-time environment.

The future work

1) Following are some of the areas where further research work can be taken up to improve the droop control performance.
2) Using a new type of algorithm for meta-heuristic optimization and apply it to the microgrid system.
3) Employing another type of control approach such as Sliding-mode voltage control.
4) Study into the use of droop control in DC microgrids.

Published Paper

1) M. A. Ebrahim, R. M. A. Fattah, E. M. Saied, S. M. A. Maksoud, and H. El Khashab, “Real-Time Implementation of Self-Adaptive Salp Swarm Optimization-based Microgrid Droop Control,” *IEEE Access*, vol. 8, pp. 1-1, 2020, doi: 10.1109/access.2020.3030160.
2) M. A. Ebrahim, R. M. A. Fattah, E. M. Saied, S. M. A. Maksoud, and H. El Khashab, “An Islanded Microgrid Droop Control using Henry Gas Solubility Optimization” International Journal of Innovative Technology and Exploring Engineering, ISSN: 2278-3075, Volume-10 Issue-3, January 2021
3) Chapter “ Salp Swarm Optimization with Self-Adaptive Mechanism for Optimal Droop Control Design” Book title: Electric Power Conversion (ISBN 978-1-83969-389-2 “, IntechOpen , accepted.


Thank you