INTEGRATION OF DISTRIBUTED GENERATORS AND STORAGE DEVICE IN MICRO GRID

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Outlines

List of Publication

List of Paper Presented at Conferences

1. P. Upadhyay and S. Joshi, “Optimal summation of natural power distributed resources in grid connected microgrid,” in 2019 International Conference on Information Technology (ICIT). IEEE, 2019, pp. 400–405..
2. P. A. Upadhyay and S. K. Joshi, "Models and methods for integrating green power distributed generators in microgrid,” 2017 52nd International Universities Power Engineering Conference (UPEC), 2017, pp. 1-6, doi: 10.1109/UPEC.2017.823195

List of Paper published in Journal

1. Upadhyay Parul, and Satish Joshi. (2020) '"Computation of Power Generation of Green Power Unit based on Probability Distribution Parameter.” International Journal of Recent Technology and Engineering (IJRTE), 4447-4452. doi:10.35940/ijrte.E6677.038620 .

List of Paper Submitted to the Reputed Journals (Under Review)

1. Upadhyay Parul, Joshi S.K. Integration of Natural Power Resources combined with Energy storage device in Microgrid, Journal of The Institution of Engineers (India): Series B.

Introduction

The main work behind the integration of distributed generators and storage devices in microgrid is

- Determine location and size of DG (Renewable and non renewable Distributed Generators) with/without storage device in microgrid for minimization of cost and losses
- Analyze the operation of microgrid in various scenario considering uncertain nature of renewable sources

Introduction

The Motivation for the Work:

- Global warming
- Today's Power sector scenario
- Growing use of renewable generators
- Expansion of the existing distribution network (DN), Transforming DN into a microgrid,
- Development of new micro grid and smart-grid
- India is richest in matter of solar energy

Reviewed literature work has proposed a framework to integrate renewable generators in transmission power systems to meet various goals like minimizing energy losses in terms of loss index, loss sensitivity index and annual network losses, improving voltage stability and maximizing reliability etc. A Few work has been focused on distributed systems as a microgrid with combination of renewable-nonrenewable DG with their nature.

Introduction

To integrate non-renewable and renewable DG considering its type, characteristics, availability, and nature of its sources
Work has been carried out in two steps:

- Analysis of sources of renewable distributed generator and modeling of their intermittent nature.

Wind generation unit
Solar generation unit

- Development of optimization strategy for Distributed generator placement and size in microgrid

Backward forward load flow
Particle swarm optimsation
Levy flight Particle swarm optimsation

Wind Power Generation Unit

The wind power estimation is first step to allocate wind unit in microgrid; wind power estimation $p_{wg}(v)$ depends

- speed of wind,wind turbine characteristics/wind unit rated capacity, tropology
- wind turbine performance curve or standard curve fitting technique

Statistical model has been used for characterized wind speed uncertainty [5], [1], [12];:

- Normal Distribution Function (NDF)
- Cumulative Distribution Function (cdf)
- Probability Distribution Function (pdf) : Weibull pdf, Ray leigh pdf
- Regression time series model

Wind Power Generation Unit model

Here wind power $p_{wg}(v)$ is modelled in Two way:

1. Weibull pdf with constant shape factor and slotwise shape factor
2. wind speed distribution into four states of wind speed range around the mean speed of specified time laps.

Weibull pdf for power estimation

Power estimation is done on the basis weibull probability curve.

$$F_w(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{1}$$

weibull pdf has been obtained for all time slots/day/quarter
at fixed value of shape parameter ($k = 1.6$)
at slotwise shape factor k and c which is given by:
$c = \left(\frac{v_m}{\left(\Gamma(1+\frac{1}{k}\right)}\right)$, $k = \left(\frac{v_{sd}}{v_m}\right)^{-1.089}$

Table: Wind statistics of the Quarter January to March

Time slot no	slot/day	(v_m) m/s	v_{sd} m/s	k	c
1	00 to 3:00	5.386	3.515	1.59160	6.00445
2	3:00 to 6:00	5.687	3.759	1.5696	6.33155
3	6:00 to 9:00	5.7463	3.569	1.67977	6.43482
4	9:00 to 12:00	5.187	3.489	1.47552	5.51293
5	12:00 to 15:00	4.832	3.137	1.60069	5.38984
6	15:00 to 18:00	3.678	3.042	1.2296	3.93368
7	18:00 to 21:00	4.163	3.851	1.60069	4.2992
8	21:00 to 24:00	5.786	3.102	1.97166	6.5267

Table: Wind statistics of the Quarter April to June

Time slot no	slot/day	(v_m) m/s	v_{sd} m/s	k	c
1	00 to 3:00	6.823	3.812	1.88505	7.68702
2	3:00 to 6:00	5.926	2.635	2.41717	6.68396
3	6:00 to 9:00	5.491	3.147	1.83345	6.18007
4	9:00 to 12:00	4.728	3.257	1.500600972	5.23762
5	12:00 to 15:00	4.925	3.777	1.158979647	5.360253
6	15:00 to 18:00	5.092	2.421	2.247145205	5.7491249
7	18:00 to 21:00	5.235	3.632	1.489023156	5.79349
8	21:00 to 24:00	6.233	3.023	2.199014175	7.03816

Table: Wind statistics of the Quarter July to September

Time slot no	slot/day	(v_m) m/s	v_{sd} m/s	k	c
1	00 to 3:00	5.142	4.763	1.110223745	7.68702
2	3:00 to 6:00	5.736	4.215	1.370828345	6.68396
3	6:00 to 9:00	5.443	5.213	1.5599	6.18007
4	9:00 to 12:00	4.821	4.294	1.134356	5.45010395
5	12:00 to 15:00	5.631	3.952	1.470462	6.22293
6	15:00 to 18:00	7.542	2.421	2.0227	5.217244
7	18:00 to 21:00	7.123	3.634	1.8348	5.79349
8	21:00 to 24:00	6.345	3.543	2.13936	7.03816

Table: Wind statistics of the Quarter October to December

Time slot no	slot/day	(v_m) m/s	v_{sd} m/s	k	c
1	00 to 3:00	4.846	1.944157471	2.70367	5.4492
2	3:00 to 6:00	5.0251	1.871823212	2.93123	5.6328
3	6:00 to 9:00	5.008	1.783131937	3.0789	5.60178
4	9:00 to 12:00	5.334	2.937709103	1.91469	4.46559
5	12:00 to 15:00	4.2607	2.225679081	2.02823	4.808916
6	15:00 to 18:00	3.5615	2.043609313	1.83107	4.00799
7	18:00 to 21:00	3.8217	1.833386023	2.2253	4.31489
8	21:00 to 24:00	4.3908	1.787964011	2.66018	4.94014

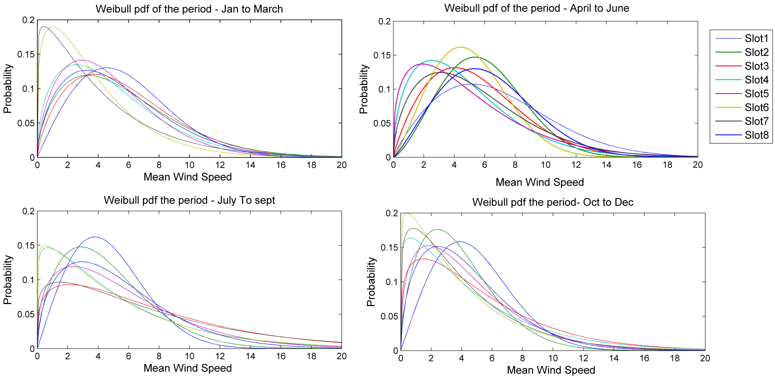


Figure: Weibull pdf (f vs wind speed(m/s) for the period of four Quarters,slotwise wind turbine chosen for estimation of power generation using model1 and modal2

- Rated power: 1000 KW,
- Cut in speed:3.5 m/s,
- Rated speed :12 m/s
- Cut out speed: 20 m/s
- Assume: windmill blades move as-per wind direction

Wind Power Generation Unit model1

The basic model of wind power generation.

$$p_{wg}(v) = \begin{cases} p_{sr}, & v_{sr} < v \leq v_o; \\ P_{sr} \frac{v - v_i}{v_{sr} - v_o} & v_i < v \leq v_{sr}; \\ 0, & v \leq v_i \text{ or } v \geq v_o; \end{cases} \quad (2)$$

The modified model in this work is

$$p_{wg}(v_m) = \begin{cases} p_{sr}, & v_{sr} < v_m \leq v_o; \\ P_{sr} \frac{v_m - v_i}{v_{sr} - v_o} & v_i < v_m \leq v_{sr}; \\ 0, & v_m \leq v_i \text{ or } v_m \geq v_o; \end{cases} \quad (3)$$

The probable power production per one slot with variable speed between cut in speed and cutout speed around mean wind speed has been computed by:

$$p_{wg} = p_{w_{avg}}(v_m) \int_{v_{ci}}^{v_{co}} f(v)\, dv \quad (4)$$

The power generation for the specified wind turbine is computed using the expression 4

Table: Comparison of probable power potential of all Quarters in kw with slot wise shape index(k)and fixed shape index(k=1.6)

Time slot no	Jan to March		April to June		July to Sept		Octo to Dec	
	slotwise k	k=1.6	slotwise k	k=1.6	slotwise k	k=1.6	slotwise k	k=1.6
1	121.93	137.16	241.34	260.67	166.52	99.55	70.46	73.41
2	140.292	149.829	235.162	200.13	103.30	78.23	27.51	79.67
3	152.00	156.10	183.26	173.10	98.59	71.31	100.00	67.22
4	89.14	124.38	159.42	155.00	62.45	57.88	48.84	49.19
5	84.30	105.13	115.48	128.09	122.22	92.37	51.85	17.96
6	21.23	37.78	174.19	137.00	187.61	92.37	3.38	3.83
7	28.70	55.1027	163.13	173.10	174.74	106.80	20.14	17.01
8	128.51	117.97	238.96	217.89	177.29	114.09	70.1	43.41

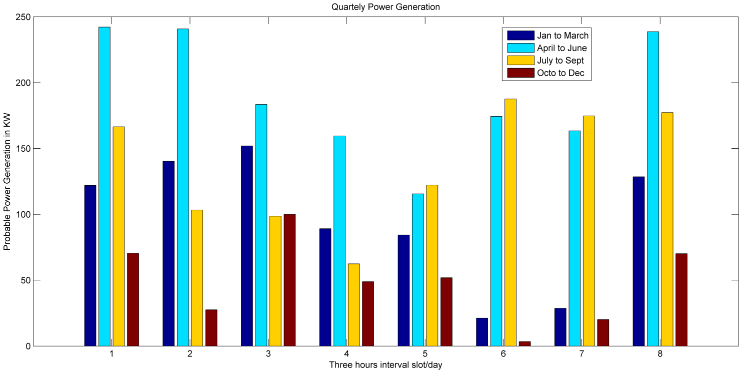


Figure: Probable power production for the period of four Quarters,slotwise k

Table: Probable energy generation/day/Quarters in (KWH)

value of k	Jan-March	April-June	July-Sept	Octo-Dec
k is slotwise	2298.4	4553.8	3278.3	1177
$k = 1.6$	6152	8574	4765	2250
$k = 2$	7056	11560	5875	2734

Wind Power Generation Unit model 2

$$p_{wg} = \sum_{i}^{st} p_{wg_i}(v_{mst}) \int_{v_1}^{v_2} f(v)\,dv \quad v_1, v_2 \geq v_{ci} \quad and \quad v_1, v_2 \leq v_{co} \quad (5)$$

where, v_1 lower limit of wind speed specified wind state;
v_2 is upper limit of wind speed the state,
v_{mst} is average wind speed of the state;

Table: Wind speed state

state	v_1	v_2
1	$v_m - 2(v_{sd})$	$v_m - (v_{sd})$
2	$v_m - (v_{sd})$	v_m
3	v_m	$v_m + (v_{sd})$
4	$v_m + (v_{sd})$	$v_m + 2(v_{sd})$

Hourly average wind power generation/day/specific period using model 2

Table: Wind parameters and energy generated considering wind states

	Time period			
Wind statistics	Jan- march	April-June	July- Sept	Octo- Dec
mean wind speed	5.4	6.45	5.59	4.5
Standard deviation	5.4	4.5	4.07	3.39
Shape parameter(k)	1.02	1.34	1.41	1.3
Scale parameter(c)	5.5455	7.0329	6.1419	4.9146
Energy generated/day(KWH)	2319	4784	3312	1256
Energy generated/day(KWH) k is slotwise	2298.4	4553.8	3278.3	1177

Solar Power Generation Unit Model

The development of solar power generation model is required to analyze the potential of solar energy for a specific location.
The paramount importance in assessing solar potential is solar irradiation daily, monthly and seasonal variation. The accurate measurement of variable solar radiation is impossible for all periods.
The statically analysis can be helpful in determining solar potential For power grid planning. [1] [2] [3] [5] [6][14].
Here the Solar power generation is modeled in Two way:
Based on hourly mean solar irradiation and hourly beta pdf
Based on four state of solar irradiation/hour/day with best fitted Beta pdf.

- hourly beta pdf for each season were obtained, and probable power was computed based on that probability ranging from zero to maximum irradiation.
- probable power generation has been integrated for four states around the mean solar radiation -s_m

Beta probability distribution

$$F_b(s) = \begin{cases} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta))} s^{(\alpha-1)} (1-s)^{(\beta-1)}, & \text{if } 0 \leq s \leq 1, \alpha, \beta > 0 \\ 0, & otherwise \end{cases} \tag{6}$$

Where, $F_b(s)$ is the Beta distribution function of random variable of solar irradiance s (kW/m^2), $\alpha \geq 0$ and $\beta \geq 0$ are parameters of beta distribution; These parameters are computed using mean (μ) and variance(σ) of time series historical data of solar irradiance as per equation: 7.
The $F_b(s)$ is 0 outside the interval[0,1].

$$\beta = (1-\mu)\left(\frac{\mu(1+\mu)}{\sigma^2} - 1\right); \quad \alpha = \frac{\mu * \beta}{1-\mu} \tag{7}$$

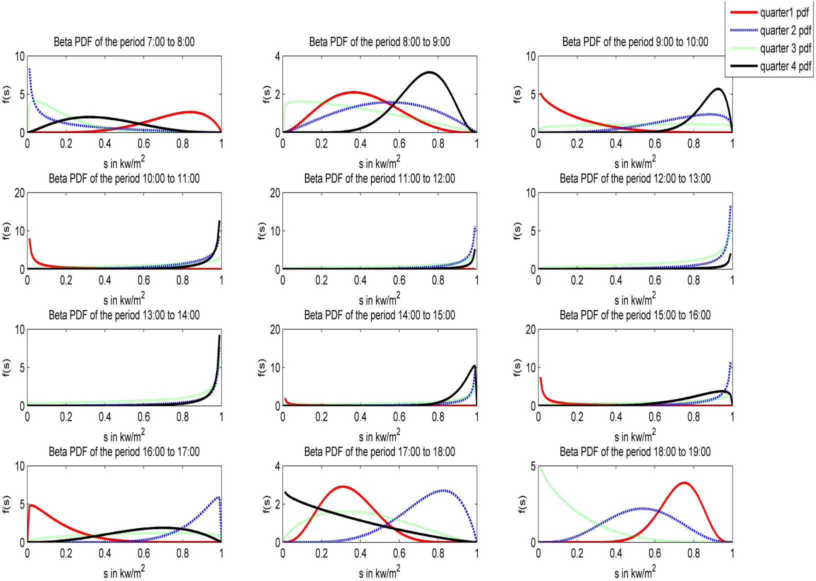


Figure: Beta probability distribution at the discrete value of parameters

Solar Power Generation model1

$$P_O = N * FF * V_y * I_y \tag{8}$$

$FF = \frac{V_{Mpp} * I_{Mpp}}{V_{oc} * I_{sc}}, V_y = V_{oc} - k_v - T_{c_y};$
$I_y = s\left[I_{sc} + k_i \times \left(T_{c_y} - 1\right)\right];$
$T_{c_y} = T_A + s\frac{(N_{0T} - 20)}{0.8}$
The solar irradiation-s has been replaced by solar hourly mean radiation for the specific period

$$P_O(s_m) = N * FF * V_y(s_m) * I_y(s_m) \tag{9}$$

The probable power production per one hour

$$p_{sg} = p_{s_{avg}}(s_m) \int_0^{s_m} f_b(s)\, ds \tag{10}$$

The estimation of energy generation per day has been done by expression

$$E_{sg} = \sum_{i}^{h} p_{wg_i} \tag{11}$$

Solar power generation model 2

$$p_{sg} = \sum_{i}^{st} p_{sg}(s_{mst}) \int_{s_1}^{s_2} f(s)\, ds; \quad s_1 \geq 0 and s_2 \leq 1 \qquad (12)$$

where, s_1 and s_2 is lower limit and upper limit of solar irradiation state respectively.
s_{mst} is average solar irradiation of the state;

Table: Solar irradiation state

state	s_1	s_2
1	$s_m - 2(s_{sd})$	$s_m - (s_{sd})$
2	$s_m - (s_{sd})$	s_m
3	s_m	$s_m + (s_{sd})$
4	$s_m + (s_{sd})$	$s_m + 2(s_{sd})$

solar unit

- maximum power point voltage $V_{mpp} = 31$ V;
- maximum power point current$I_{mpp} = 8.08$ amp;
- open circuit voltage $V_{oc} = 37.6$ V;
- short circuit current I_{sc} =8.78 amp;
- voltage coefficient $k_v = 0.04$;
- current coefficient $k_i = 0.012$;
- normal operating cell temperature $N_{ot} = 45.7$;
- no of modules $N = 400$
- system technical losses= 28

Solar Power Generation curve

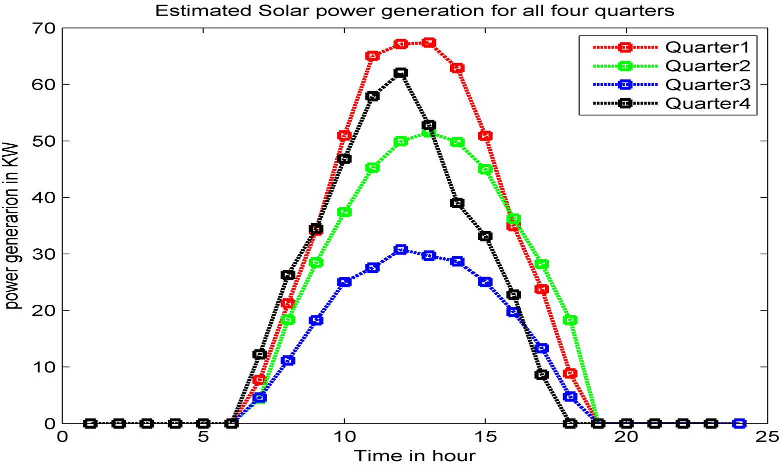


Figure: Probable Solar Power Generation of each Quarter

Comparison of Solar energy

Time	Jan to March		April to June		July to Sept		Octo to Dec	
slot	p_{sg} at S_m	p_{sg} at state wiseS_m	p_{sg} at S_m	p_{sg} at state wiseS_m	p_{sg} at S_m	p_{sg} at state wiseS_m	p_{sg} at S_m	p_{sg} at state wiseS_m
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	7.71	15.4	18.36	27.55	11.15	7.57	26.27	22.17
9	34.14	54.82	28.49	42.61	18.23	13.45	34.50	36.08
10	50.98	63.19	37.44	50.76	25.03	13.38	46.83	44.63
11	65.03	66.86	45.27	56.99	27.59	11.79	57.92	46.26
12	67.12	68.21	49.95	59.57	30.78	0.00	62.07	47.85
13	67.39	68.19	51.51	59.87	29.69	0.00	52.80	46.21
14	62.90	66.78	49.81	58.70	28.67	9.42	39.03	46.78
15	50.89	62.92	44.98	55.53	25.06	13.64	33.15	44.38
16	34.91	59.28	36.23	49.98	19.71	13.14	22.79	38.34
17	23.77	44.06	28.22	41.80	13.29	7.90	8.61	26.32
18	8.84	17.62	18.32	26.27	4.77	2.97	0.00	10.31
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$E_{sg_{ave}/day}$	494.92	627.61	412.96	536.81	238.58	95.95	396.18	419.05
$E_{sg_{ave}/hour}$	41.24	52.30	34.41	44.73	19.88	8.00	33.01	34.92

Introduction of Microgrid

The microgrid is a low-medium voltage distribution grid equipped with sensing, controlling, and communicating technology that is specifically located at consumer premises or near the load center. The advanced distribution system known as a microgrid is comprised of a small number of distributed energy resources (DERs), both natural and/or conventional sources such as photovoltaic, wind power, hydro, internal combustion engine, microturbine, and gas turbine, as well as a cluster of loads [10].

Rapid advancements in power electronics and communication technology are helping to shape the microgrid.

Introduction of Microgrid

A clear definition of a microgrid has been established in study report [8]. It is a power distribution network comprising of multiple electric loads and distributed energy resources and characterized by all of the following:

- The ability to operate independently or in conjunction with a grid;
- One or more points of common coupling (PCC's) to the grid;
- The network should have the ability to operate all distributed energy resources (DER), including load and energy storage components, in a controlled and coordinated fashion, either while connected to the maingrid or operating independently.
- The network should have the ability to interact with the grid in real time and thereby optimize system performance and operational savings.

Introduction of Microgrid

The main objective of a microgrid:
To provide reliable, cost-effective, and high-quality power to critical loads.
It is possible to achieve this by integrating and optimizing the various energy sources.
An algorithm has been proposed to embed natural power resources combined with storage and microturbines in distribution systems for minimize grid losses.
The microgrid's reliance on the main grid has been examined in view of the uncertain nature of renewable resources.

Microgrid model

The radial distribution system has been modeled for microgrid deployment. [16] [17]

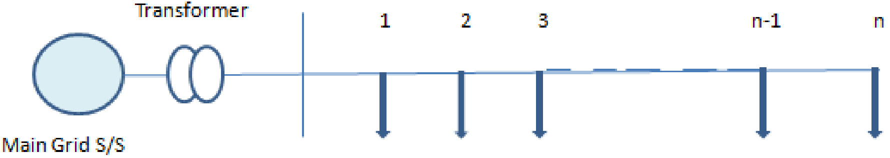


Figure: Single line diagram of radial distribution system.

Microgrid model

The distribution system is considered a microgrid, with Natural Power Distributed Generators (NPDG) such as wind and solar units installed at the bus, say i/k.

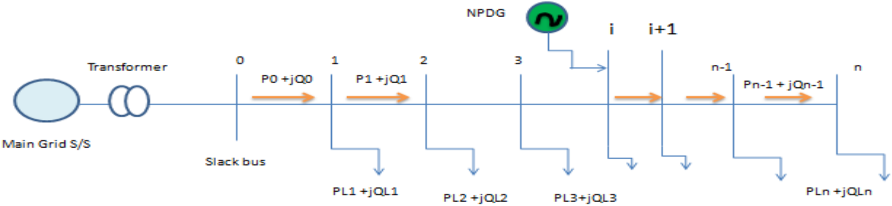


Figure: DG placement at bus i.

Microgrid model-Backward Flow

$$P_{n-1} = P_n + r_{(n,n-1)} \left(\frac{P_n^2 + Q_n^2}{V_n^2} \right) \tag{13}$$

$$Q_{n-1} = Q_n + x_{(n,n-1)} \left(\frac{P_n^2 + Q_n^2}{V_n^2} \right) \tag{14}$$

$$V_{n-1} = (V_n) + \left(\frac{r_{(n,n-1)} P_n + x_{(n,n-1)} Q_n}{V_n^2} \right) \tag{15}$$

$$I_{b(n-1,n)} = \frac{S_n^*}{V_n} \quad where, \qquad S_n = P_n + jQ_n \tag{16}$$

The voltage at any other bus i becomes;

$$V_{(i+1)} = V_i - \left(\frac{r_{(i,i+1)} P_i + x_{(i,i+1)} Q_i}{V_i^2} \right) \tag{17}$$

Microgrid model-Forward Flow

The branch current will be;

$$I_b(i+1,i) = \frac{V_i - V_{(i+1)}}{Z_{(i,i+1)}} \tag{18}$$

.

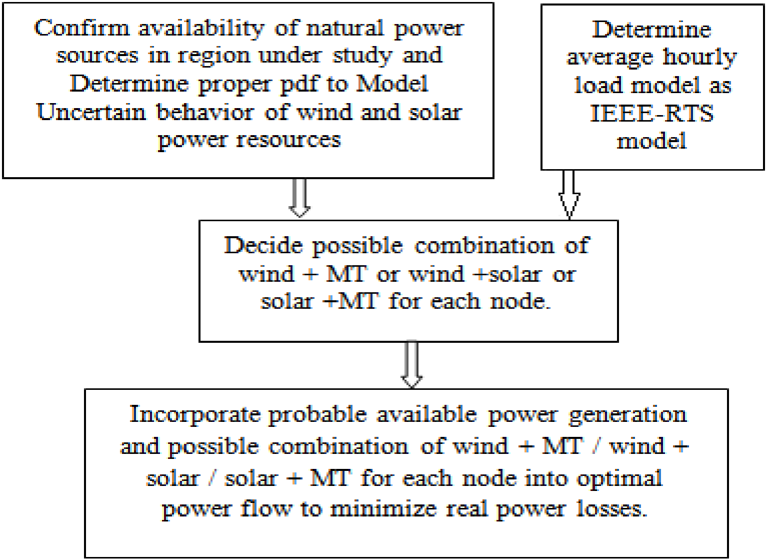
$$P_{k+1} = P'_k - r_{k,k+1}\left(\frac{(P'_k)^2 + (Q'_k)^2}{V_k^2}\right) \quad where \quad P'_k = P_k + P_{DGk} - P_{Lk} \tag{19}$$

$$Q_{k+1} = Q'_k - x_{k,k+1}\left(\frac{(P'_k)^2 + (Q'_k)^2}{V_k^2}\right) \quad where \quad Q'_k = Q_k + Q_{DGk} - Q_{Lk} \tag{20}$$

$$V_{k+1} = V_k - \left(\frac{r_{(k,k+1)}P'_k + x_{(k,k+1)}Q'_k}{V_k^2}\right) \tag{21}$$

$$I_{b(k+1,k)} = \frac{V_k - V_{(k+1)}}{Z'_{(k,k+1)}} \tag{22}$$

Optimisation Problem formation strategy and solution



IEEE 13 node Distribution system[9]

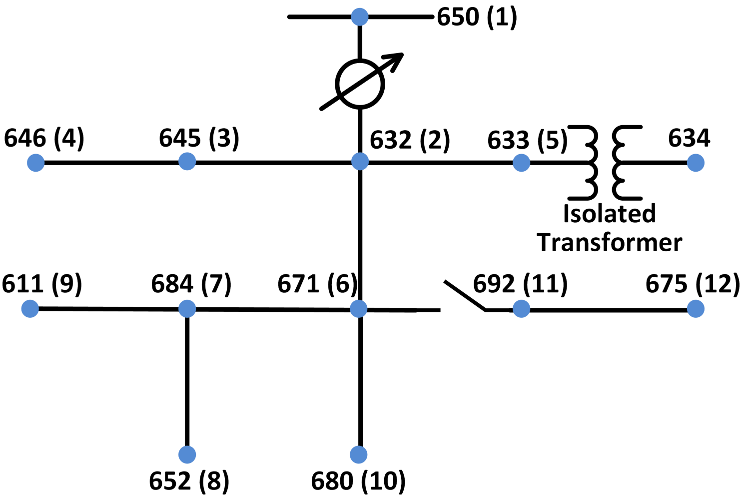


Figure: Single line diagram of IEEE-13 node system with renumbering

NPDG data

Table: Selected size of NPDG

wind based NPDG	solar based NPDG	micro turbine
Rated power :2.1 MW Rated speed :11 m/s Cut-in speed:3.5 m/s Cut-out speed: 25m/s hub height :79 m	Rated Power: 100MW No of module: 400 nos Module capacity: 250wp System losses : 28%	Rated Power: 500MW Rated voltage :4.15KV

Load data and Losses

The total connected load of the system is 1760.7 KW. which is peak load. The hourly average load over one day has been generated as a percentage of peak load by computing the average of daily load profile over 24 hours.[3],[15]

Table: Seasonal hourly average load

season	system load in kw
winter	1037
summer	1459
spring	920
fall	865

The maximum feeder current limit is 1KA. Total network losses computed after backward forward load flow are: 19.63 KW without DG Placement.

$$G_{loss} = \sum_{ij=1}^{n_b} I_{ij}^2 r_{ij} \quad where, I_{ij} = I_{b(k,k+1)} \tag{23}$$

Application of Backward Forward Load Flow to Radial Distribution System

The load flow analysis was carried out for all placement combinations say; $\binom{n}{r}$.where, n= number of buses and r= The discrete number of DG units. The conclusion from Load Flow Result

- When only two DGs are chosen for placement, Bus nos. 4 and 6 are the best locations for NPDG placement and losses were reduced. It is up to 35 to 50 percent of total grid losses in each season
- When three DGs are chosen, the third-best placement is bus number 12, and losses are reduced It is up to 20% to 25% of total grid losses in each season
- Bus numbers 4,3/9,12,6 are the best locations for the placement of four DG scheduled, with losses 10% to 20% of total in losses each season.

NPDG Combination

Table: Combination of NPDG

Combination set cases	solar based NPDG	wind based NPDG	micro turbine
Case 1	1	0	1
case 2	0	1	1
case 3	0	2	1
case 4	1	1	1
case 5	1	2	1
case 6	0	3	1
case 7	3	0	1

Table: Optimal placement of DG for Each Combination of NPDG.

season	NPDG set cases	best placement	G_{losses} without NPDG placement	G_{losses} after NPDG placement
winter	case 1	4,6	5.37	2.09
	case 2	4,6		1.71
	case 3	12,4,6		1.245
	case 4	12,4,6		1.55
	case 5	12,3,4,6		1.21
	case 6	12,9,4,6		0.535
	case 7	12,9,4,6		0.936
summer	case 1	4,6	10.92	5.34
	case 2	4,6		3.27
	case 3	12,4,6		2.04
	case 4	12,4,6		4,19
	case 5	4,3,7,12		1.19
	case 6	12,3/9,4,6		0.65
	case 7	12,3,4,6		3.436
spring	case 1	4,6	4.23	1.42
	case 2	4,6		1.03
	case 3	12,4,6		0.87
	case 4	12,4,6		1.69
	case 5	4,3/9,6,12		0.79
	case 6	12,3,4,6		0.345
	case 7	12,3,4,6		0.986
fall	case 1	4,6	3.74	1.33
	case 2	4,6		0.94
	case 3	12,4,6		0.86
	case 4	12,4,6		1.01
	case 5	4,3,12,6		0.97
	case 6	12,3/9,4,6		0.325
	case 7	12,3/9,4,6		1.0593

Objective Function

$$OF_1 = \sum_{ij=1}^{n_t} N_{loss}^t \tag{24}$$

$$OF_2 = DF^t = \frac{\frac{s_p}{P_D}(t)}{\sum_{ij=1}^{n_d} \frac{P_{npdg_i} + P_{mt_i}}{P_D}} \tag{25}$$

$$\begin{aligned} F =& OF_1^t + OF_2^t + ((V_i)^{max} - (V_i))^2 + ((V_i) - (V_i)^{min})^2 \\ &+ ((I_{ij})^{max} - (I_{ij}))^2 + ((I_{ij}) - (I_{ij})^{min})^2 \end{aligned} \tag{26}$$

Constraints

- Nodal voltage constraints: $V^{min} \leq V_i \leq V^{max}$
- Feeder current flow constraints: $-I^{max}(I^{max}) \leq I_{ij} \leq I^{max}$
- Power generation limits of NPDG: $P_{WG} = \sum_{i=1}^{N_d} n_{wgi} * P_{wratedi}$;
  where,
  n_{wgi}= no of possible wind unit; $P_{wratedi} = windunitratedcapacity$;
- $P_{SG} = \sum_{i=1}^{N_d} n_{sgi} * P_{sratedi}$; $n_{sgi} = noofpossiblesolarunit$; $P_{sratedi} = solarunitratedcapacity$;
- $P_{MTG} = \sum_{i=1}^{N_d} n_{mtgi} * P_{mtratedi}$

Table: Optimal Placement of DG for Case 6 using PSO.

Season	Best placement node no with hourly average power generation required in kW				Details DG placement
	4	6	3/9	12	
Winter	180	319	180	180	wind unit at node 4,9,12 MT unit at node 6
Summer	327	500	211	277	
Spring	217	343	133	226	wind unit at node 4,3,12 MT unit at node 6
Fall	211	290	143	251	

Table: Optimal placement of DG for Case 5 of NPDG using PSO

season	Best placement node NO with hourly average power generation required in kW				Details DG placement
	4	6	3/9	12	
Winter	180	500	180	45.63	wind unit at node 4,12 Solar at node 3, MT unit at node 6
Summer	417.9	500	288.5	44.7	
Spring	202.9	470.4	133.2	42.3	wind unit at node 4,12 Solar at node 9, MT unit at node 6
Fall	253	432	125	19.8	

Table: Optimal placement of DG for case 7 of NPDG using PSO.

season	Best placement node NO with hourly average power generation required in kW				Details DG placement
	4	6	9	12	
Winter	45	500	45	45	solar unit at node 4,9,12 MT unit at node 6
Summer	60	500	60	60	
Spring	40	500	40	40	solar unit at node 3,4,12 MT unit at node 6
Fall	15	500	15	15	

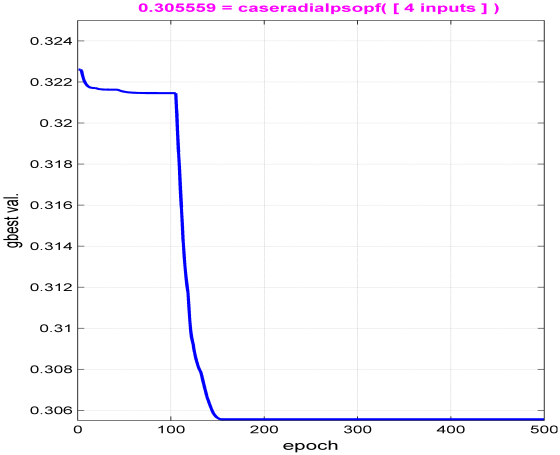


Figure: G_{best} with wind unit placement in spring Season

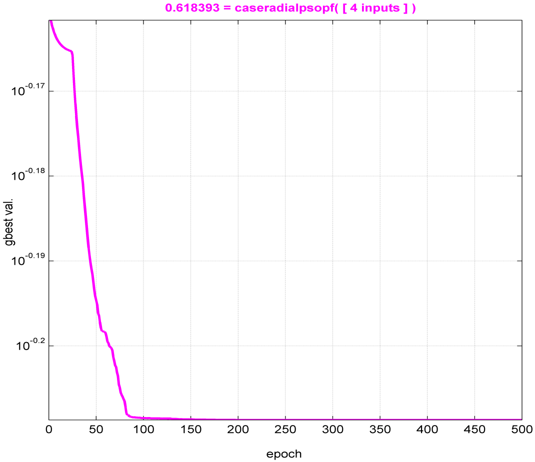


Figure: G_{best} with wind and solar unit placement in spring Season

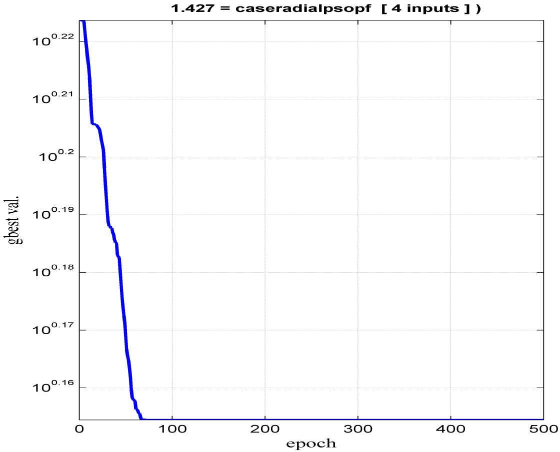


Figure: G_{best} with solar unit placement in spring Season

Table: Value of Optimised Function.

seasonal Time Lapse	g_{best}			S/S dependency factor			G_{losses} in KW		
	solar MT	wind MT	wind solar MT	solar MT	wind MT	Wind solar MT	solar MT	wind MT	Wind solar MT
winter	1.884	0.77	1.16	0.63	0.17	0.22	0.7	0.45	0.53
summer	4.565	0.663	1.496	1.146	0.029	0.14	3.41	0.63	1.93
spring	1.42	0.30	0.61	0.48	-0.03	0.078	0.94	0.33	0.69
fall	6.33	0.29	0.62	0.58	-0.034	0.409	1.049	0.32	0.64

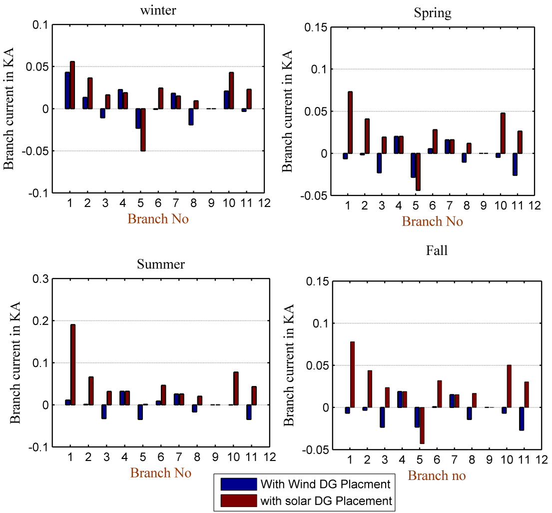


Figure: Reverse current flow in case 6

An Enhanced Particle Swarm Optimizer Algorithm with Levy flight

Particle swarm optimization is one of the well-known nature inspired evolutionary algorithms.

The main drawback of (PSO)is: Trapping of local minima and law convergence rate for multi objective problems

A lot of hybrid algorithms have been developed for multi model optimization problems to overcome these drawbacks of PSO

Here PSO algorithm with levy flight distribution presents to achieve optimal planning of microgrid with Dg integration

The LEVYPSO have been used in 2017, 2018, 2019 Grid Optimization Competition.[11][13]

Levy flight PSO

$$V_{i,D}^{t+1} = w_t V_{i,D}^{t} + c_1 \times rd_1 * \left(p_{best_{i,D}}^{t} - X_{i,D}^{t}\right) + c_2 \times rd_2 * \left(gbest_{i,D}^{t} - X_{i,D}^{t}\right) \tag{27}$$

$$X_{i,D}^{t+1} = X_{i,D}^{t} + V_{i,D}^{t+1} \tag{28}$$

c_1 is the cognitive weight factor, and c_2 is the social weighting factor. The value of the inertia coefficient weight between ($wmax = 0.9$) and ($wmin = 0.4$).

Levy flight PSO

The levy distribution has been obeyed to choose the direction and generation of random numbers [4] [7].

$$L(y) \sim |y|^{-1-\gamma}, \; where \; 0 < \gamma < 2 \tag{29}$$

Levy distribution is defined in simple mathematics form as,

$$w_t = \sim Levy_{pdf}(w, \mu, \beta) \tag{30}$$

In this suggested LEVY-PSO, the larger value of w has been attained on occasion.

$$V_{i,D}^{t+1} = B_V \left[w_t V_{i,D}^{t} + c_1 \times rd_1 * \left(p_{best_{i,D}}^{t} - X_{i,D}^{t} \right) + c_2 \times rd_2 * \left(g_{best_{i,D}}^{t} - X_{i,D}^{t} \right) \right] \tag{31}$$

$$X_{i,D}^{t+1} = B_X \; \left(\; X_{i,D}^{t} + V_{i,D}^{t+1} \right) \tag{32}$$

However,Due to larger value of w, the increased velocity and distance travelled may be excessive. Therefore, limits are established in order to avoid extended travelling distances as per (31)and (32)

Objective Function

The objective function, which included economic and technical functions is forulated as follows:

$$min(F_e, F_T),\ p_{dg_i} \in [\frac{p_{dg_i}^{\min}}{day}\ \frac{p_{dg_i}^{max}}{day}] \qquad (33)$$

Where, i = 1, 2, 3 . . . ..n number of distributed generators

$$F_e = We\left(C_O(U_{dg}) + C_U(p_{dg_i}^{\frac{aava/h}{eava/h}}) + C_{O_{SD}}(P_{SD}^{\frac{cha}{dis}})\right) \qquad (34)$$

$$C_O(U_{dg}) = \alpha_w * \sum_{i=1}^{n_{wdg}} U_{wdg_i} + \alpha_s * \sum_{i=1}^{n_{sdg}} U_{sdg_i} + C_O(U_{mtdg_i}) \qquad (35)$$

Objective Function

In 35,

$$C_O\left(U_{mtdg_i}\right) = \alpha_{mt} * \sum_{i=1}^{n_{mtdg}} U_{mtdg_i} + \alpha_{mt_1} * \sum_{i=1}^{n_{mtdg}} \left(U_{mtdg_i}\right)^2 + \alpha_{mt_0}$$

$$C_U\left(p_{dg_i}^{\frac{aava/h}{eava/h}}\right) = C_{u_i} \sum_{i=1}^{n_{w/sdg}} \left(p_{dg\frac{w}{s}i}^{\frac{eava}{h}} \pm p_{dg\frac{w}{s}i}^{\frac{aava}{h}}\right) \tag{36}$$

$$P_{SD}^{Char/dis} = \pm \frac{\left(SOC^{t_2} - SOC^{t_1}\right)\ E_{SD_{r_i}}}{t_2 - t_1} \tag{37}$$

$$C_{O_{SD}}\left(P_{SD}^{\frac{cha}{dis}}\right) = C_{char/dis} * \sum_{i=1}^{n_{w/sdg}} \left(p_{SD_{w/s_i}}^{\frac{cha}{dis}}\right) \tag{38}$$

Technical objective function

The F_t is formulated for optimal technical operation model of microgrid with integration of renewable and non renewable DG expressed as;

$$F_t = Wt\left(\sum_{ij=1}^{nb} P_{blosses_{ij}}\left(V_i, V_j\right) + |SBDI|\right) \tag{39}$$

The SBDI is an index that reflects the amount of power exchanged from substation to microgrid to balance generation-load demand when RES-DG + storage devices provide inadequate or surplus power. When power generation exceeds load demand, electricity is transmitted to the substation, resulting in a negative SBDI. The SBDI is defined as follows:

$$SBDI = \left(\sum_{i=1}^{n_{dg}} P_{dg_i(w,s,mt)} \pm P_{SD_i} - \sum_{i=1}^{nb} P_{Li}\right) / \sum_{i=1}^{nb} P_{Li} \tag{40}$$

The formula for branch current losses is stated as;

$$P_{blosses_{ij}}\left(V_i, V_j\right) = \left(\hat{V}_i - \hat{V}_j\right)^2 * G_{ij};\ \forall\ \hat{V}_i = V_i < \delta_i\ \ \hat{V}_j = V_j < \delta_j \tag{41}$$

System constraints

Power balance at each node:

$$P_i \ (V_i, \delta_i) = 0 \qquad \forall \ V_i \epsilon \left[V_{max} \quad , \quad V_{min} \ \right] \quad \forall \ \delta_i \epsilon \left[\delta_{max} \quad , \quad \delta_{min} \ \right]$$
$$Q_i \ (V_i, \delta_i) = 0 \qquad \forall \ V_i \epsilon \left[V_{max} \quad , \quad V_{min} \ \right] \quad \forall \ \delta_i \epsilon \left[\delta_{max} \quad , \quad \delta_{min} \ \right]$$

Branch current flow constraint: $-I_{\min} \leq I_{ij} \leq I_{\max}$
DG unit and size constraint:
Wind DG Unit:

$$P_{WG} = \sum_{i=1}^{nb} n_{wdg_i} * P_{WG_i}$$

Solar DG Unit:

$$P_{SG} = \sum_{i=1}^{nb} n_{sdg_i} * P_{SG_i}$$

System constraints

Micro turbine DG Unit:

$$P_{MTG} = \sum_{i=1}^{nb} n_{mtdg_i} * P_{MTG_i} \qquad Where, \quad P_{MTG}^{max} \leq P_{MTG_i} \leq P_{MTG}^{min}$$

Energy storage device operation constraint:

$$P_{SD_{min}}^{char/dis} \leq P_{SD}^{Char/dis} \leq P_{SD_{max}}^{char/dis}$$

$$SOC^{t_{min}} \leq SOC^{t} \leq SOC^{tmax}$$

Fitness function: It is structured as;

$$FF = F_e + F_T + \sigma \sum_{j=1}^{CON} max[0, K_j] \tag{42}$$

K_j is the value of j^{th} constraint.

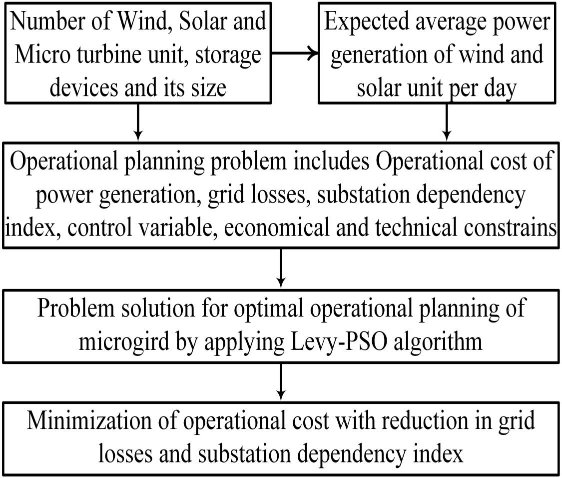


Figure: Block diagram of proposed optimal operation of Microgrid

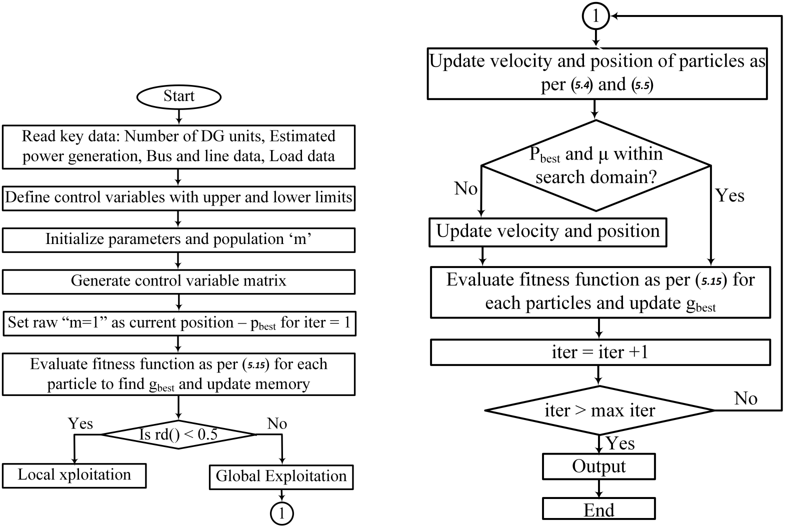


Figure: Flow chart represents proposed algorithm for optimal operation of Microgrid with Levy PSO

1. For the selected system, read essential data such as bus data, line data, and load data. Determine the discrete number of solar and wind units and the average expected generation of each unit based on geographical conditions.
2. Define control variables and examine their lower and upper bounds for the steady functioning of the microgrid. Set up a total of 24 variables, including 12 bus nodal voltages and 12 phase angles. The population 'm' is assumed to be 100.
3. Set up power generation of DG units (in this study -4 units chosen)as state variables. The 100 random values of wind and solar power generation units within expected power production limits for best combination of four DG has been loaded for program execution.
4. Because there are 28 variables and 100 population sizes, a matrix of 100 X 28 is generated for iteration step one.
5. program execution start with iteration step (iter) one and current position as per row = 1 of the matrix , which equals to current-p_{best}.
6. Evaluate fitness function as per eq:(42) for each particle.
7. Find the optimal value of the objective function for iteration step one. Then, update the memory.update row of the matrix.
8. Examine random uniform distribution to see if it indicates local or global exploitation. Update particle velocity and location using the levy flight distribution as described in eq: (31) and (32).
9. Check the p_{best} and location parameter within domain. if they are within domain evaluate fitness function for each particles and update the g_{best}.
10. Update iteration step (iter= iter+1),
11. Repeat steps 6 to 9 and record the the g_{best},
12. Load natural power unit generation again as per step (3) and repeat steps 5 to 11 for Iteration steps for 100 times,
13. Record all solution for the expected unit generation of wind and solar resources.
14. Find best solution out of these 100 iteration steps, which gives minimized grid losses, minimized levelised operating cost, SBDI with optimized controlled variables and expected average value of natural resources.

Renewable DG unit and Estimated power generation data.

Type of DG Unit	Solar unit	Wind unit	Micro turbine unit
No of units and rating	1 unit of 100 Kw	2 units,each-2MW	1 unit 500 kw.
Estimated Hourly Average power generation kw/h/day	19-26 kw/h (Low irradiation range)	228-540 kw/h (wind speed range-4m/s to 6m/s)	Max 500Kw/h
	50-70 kw/h (High irradiation range)	540-700 kw/h (wind speed range-6m/s to 9m/s)	

Cost data of natural power resources and storage devices.

Type of DG Unit/storege Device	cost coefficient
Wind turbine DG Unit	$\alpha_w = 0.0115$ \$/KWh
Solar panel DG Unit	$\alpha_s = 0.068$ \$ /kwh
Micro turbine DG Unit	α_{mt_1} =1.6e-6\$/kwh, $\alpha_{mt} = 0.2$ \$/kwh, $\alpha_{mt_0} = 1e - 6$ \$/kwh
Storage charging and discharging	$C_{(char/dis)}$ =0.375\$/kwh
Penalty for under/over estimation	0.03 \$/KWh

Various Scenario of combination of solar and wind unit as per probable power generation.

	Scenario	Estimated Solar power Generation	Estimated wind power Generation
1	Solar unit lower range of irradiation period and wind unit with estimated mean wind speed-4-6 m/s available	19-26 kwh	220-540 kwh
2	Solar unit morning/evening period(lower range of irradiation) and wind unit with estimated mean wind speed- 6-9 m/s available	19-26 kwh	540-700 kwh
3	Solar unit at higher range of irradiation period and wind unit with estimated mean wind speed– 6-9 m/s available	50-70kwh	540-700 kwh
4	Solar unit at higher range of irradiation period and wind unit with estimated mean wind speed-6 to 8 m/s available	50-70 kwh	220-540 kwh

Mean of Optimum fitness function,system operating cost,system losses and SBDI at various loading condition.

	Scenario	25% peak load KW	50% Peak load KW	75% Peak load KW	peak load KW
Best fitness function	1	16.2918	19.7538	22.0854	122.7594
	2	19.8265	12.5894	21.5289	130.6470
	3	15.2040	18.1925	24.0895	120.0811
	4	13.6568	23.0399	27.4478	118.1541
Operating cost of electricity ($/Kwh)	1	0.054636	0.106705	0.13753	0.14415
	2	0.046256	0.096204	0.1427	0.14474
	3	0.055300	0.093176	0.13430	0.142686
	4	0.13656	0.108511	0.139999	0.1414472
system active power losses(kw)	1	10.7457	8.97576	8.11740	13.4042
	2	5.14882	9.19587	6.8825	4.2434
	3	9.17070	8.40789	9.97642	2.6991
	4	7.60829	10.7179	5.9984	7.396
SBDI	1	−5.43266	−4.29652	17.771280	19.17176
	2	−13.8414	−9.9656	−2.2471	19.223
	3	−13.8141	−3.57017	−7.0972	19.46049
	4	−5.5533	−10.9262	−4.2965	17.77

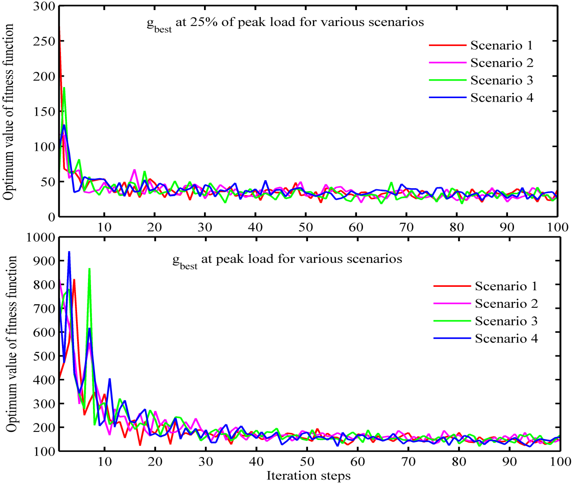


Figure: g_{best} at 25 % peak load and peak load with various scenario

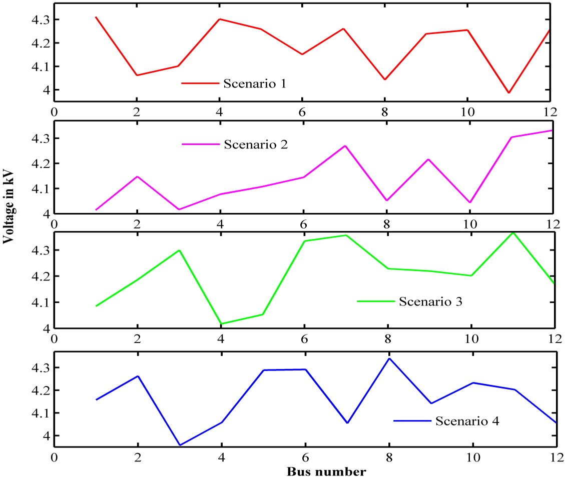


Figure: voltage at 25 % load with various scenario

Summary of finding

The wind and solar power estimation model has been proposed w in this study are effective and easier. Assumption of pdf parameter(Rayleigh) gives pessimistic result. An optimal problem strategy proposed here which help for integration of NPDG and microturbines in grid-connected microgrid or autonomous microgid in real time. The hourly average probable power generation of wind and solar units has been taken into account as the maximum power generation limit of that unit for the reliable operation of a distributed power system. In order to minimize losses and reliance on the main grid, the highest loaded node is the best optimum location for any DG having a maximum power generation limit.

Conclusion

A Levy flight Particle Swarm Optimization has been explored and implemented here to solve the proposed optimization problem of planning and operation of microgrid along with renewable and nonrenewable DGs and proved is more efficient and faster. The fitness function has been developed by including DG Levelized energy costs, grid losses, system restrictions, and microgrid reliance on the main substation. The average G_best value has been obtained for the IEEE 13 bus distribution test system.

Thankyou

Questions of Respected reviewers

Q.1

What are author's explicit contributions to the work outlined in the each chapters of this thesis?

Ans:

- The wind power model and solar power model have been developed for estimation of wind power and solar power production and compare it with basic well known model in chapter 2 and 3.
- In chapter 4, Optimisation problem has been developed and it is solved to determine optimal placement of wind unit and solar unit using developed model in previous chapters. The PSO is used for obtaining solution of the problem by applying it on IEEE-13 node network.
- In chapter 5,Optimisation problem has been modified for economic and stable operation of microgrid with random generation of wind and solar unit.The placement of DG has been determined for optimum operation of microgrid. The Levy PSO method has been used to solve proposed optimisation problem.

Q.2

What are author's contribution to the modelling aspect of the research work? Please elaborate the novel models or modeling approaches proposed in the research work?

ANS:

In this research work, two different modelling has been carried out.

- Modelling for estimation of renewable sources: The mathematical model based on four states around the mean source has been developed for getting probability of wind and solar sources and hence potential of natural power energy. The obtained result has been compared with each time slots sources. This developed model for estimation of renewable sources is more accurate and less time consuming.
- The modelling of optimisation problem :
  In chapter 4 the optimisation problem has been designed to fulfill two objective .i.e: Determine placement of DG for minimisation of grid losses and reliance on main grid. This problem has been solved by forward backward load flow and PSO.
- In chapter 5 multi objectives optimisation problem has been developed.
  The placement of DG for minimisation of grid losses, substation dependency index and cost has been determined.
  The cost include:levelised cost of renewable sources, penalty on uncertainty. This is obtained by levy Distribution in which variables are distributed between maximum and minimum limits. Instead of load flow analysis, nodal voltage, phase angle are also considered as variables including DG estimated power.

Q.3

What is a microgrid? What is an islanded operation? What is the importance of the short circuit levels when referred to islanded operation and microgrid?

ANS:

The microgrid is a low-medium voltage distribution grid equipped with sensing, controlling, and communicating technology that is specifically located at consumer premises or near the load center. The advanced distribution system known as a microgrid is comprised of a small number of distributed energy resources (DERs), both natural and/or conventional sources such as photovoltaic, wind power, hydro, internal combustion engine, microturbine, and gas turbine, as well as a cluster of loads [10].

Rapid advancements in power electronics and communication technology are helping to shape the microgrid.

What is a microgrid?

A clear definition of a microgrid has been established in study report [8]. It is a power distribution network comprising of multiple electric loads and distributed energy resources and characterized by all of the following:

- The ability to operate independently or in conjunction with a grid;
- One or more points of common coupling (PCC's) to the grid;
- The network should have the ability to operate all distributed energy resources (DER), including load and energy storage components, in a controlled and coordinated fashion, either while connected to the maingrid or operating independently.
- The network should have the ability to interact with the microgrid in real time and thereby optimize system performance and operational savings.

What is an islanded operation?

When the microgrid disconnects from the grid and operate in autonomous mode by managing the output of DG and loads to achieve power balance and control for stable operation.

In islanded mode, short circuit levels drop significantly due to the absence of strong utility grid. Most of DGs are connected through power electronic converters and these converters do not supply sufficient currents to operate current based protective devices. Some of the DGs connected to a microgrid are intermittent in nature and therefore different fault current levels may be experienced.

A grid connected microgrid has higher SCL as high inertia and current level of utility grid.e.x: A 100MW generation would provide in the region of 500-700 MVA of Short Circuit Level. Wind farms are limited by the rating their electronic component so the same level of generation may provide only around 100MVA of SCL.

Q.4

Is author aware of restrictions surrounding islanded operation in an interconnected power system? Does the author know if any OEMs provide fully supported islanded operation?

ANS:

restrictions surrounding islanded operation are:

- Immediately disconnect is restricted(anti islanding, mainly for high inertia system-like hydro)
- During islanded operation,leading to significant fluctuations of voltage and frequency which is dangerous to utility workers,End-user equipment failure/damage
- Required fine and strict frequency control,and it is necessary to monitor the voltage and frequency of the microgrid in real time.

Tata power and Adani Mumbai Electricity (AMEL) provide fully supported islanded operation for Mumbai city. The islanding system has an embedded power generation of 1,877 megawatt (Mw). The Tata power has implemented island system at Haldia,West Bangal.

Q.5 and 6

What are the basic categories of applications that an energy storage system can participate in a fully functional electricity market? Name various types of energy storage technologies currently available to participate in a fully functional electricity market. What is the oldest form of energy storage system technology in use today?

Ans:

The application of storage can be classified on the basis of utility-scale or the bulk system, customer-sited and residential and for transport. Now a days a wider array of applications for power storage has come on the electric grid and in electric vehicles (EVs)

- The basic technology of energy storage are Batteries(lithium-ion lead acid, nickel-cadmium and sodium-sulphur,zinc-air).
- Thermal (molten salt and liquid air or cryogenic storage.)
- Mechanical(flywheels and compressed air systems,)
- Pumped hydro(Hydropower pumped storage)
- Hydrogen (conversion of electricity via electrolysis for storage in tanks).

The oldest form of energy storage system technology in use today is Hydropower pumped storage.

The functional electricity market has not been studied.

Q.7

How many MWs of energy storage system is already installed to date in Gujarat and in India. What is the world's largest size of energy storage system installed to-date. Do we have any microgrid (even prototype) in operation in Gujarat or Western Grid?

ANS:

The highest installed storage capacity in the world is 400MW/1,600MWh, Moss Landing Energy Storage at site in California, US (**https://www.saurenergy.com/solar-energy-news**)

At Sun Temple Town of Modhera, Gujarat,the integrated Solar Energy Project of 6 MW with 6MVA BESS system with 18 MWh Battery energy storage system has been successfully executed. It was fully commissioned on 26th August 2021, having been completed within 1 year. Additionally, the town is solar-powered by 100 kW rooftop system on govt buildings, 50 kW Solar parking infrastructure on residential building. (**https://www.saurenergy.com/solar-energy-news/modhera-sun-temple**)

India has already crossed 100GW of installed solar and wind capacity, with another 63GW under construction. India plans to set up around 14 gigawatt-hour (GWh) grid-scale battery storage system at Khavda in Gujarat. According to the government, the Khavda renewable energy park in Kutch will be the world's largest and will finally generate 30GW of clean energy. (**https://niti.gov.in/sites/default/files/2019-10/ISGF-Report-on-Energy-Storage-System-28ESS%29-Roadmap-for-India-2019-2032.pdf**)

Q.8

What were the expected results of each problem solved in the thesis? How the author did validated the results obtained?

ANS:

In chapter 2 and 3, Natural power generation has been computed through basic and well known model which are commonly used for renewable sources analysis and their penetration/contribution/effect in power system planning. Then the Natural power generation has been carried out using proposed model for same data. The proposed model gives identical results in less computation steps.

In chapter 4, objectives are achieved by PSO and backward-forward Load flow method. The natural power resources has been modelled as per chapter 2 and 3, the result obtained by both the methods are matched. But using PSO, objective problem can solved in one run and more precise result has be obtained.

In chapter 5, optimisation problem has been modified. The randomisation of particles (variables) are followed levy distribution. Here control variables likes nodal voltage and phase angle and random estimation of natural resource have been considered on the levy distribution between predetermined limits. Result has been obtained for various scenario to prove effectiveness of levy flight PSO in power system planning.

Q.9

One of author's motivation was the less attention given to power drawn from the main grid on attaining reduced losses and improved stability, can author elaborate how the gap was addressed in this research work and what were the novel findings?

ANS:

In this research work power SBDI means substation dependency index has been proposed;

The SBDI is an index that reflects the amount of power exchanged from substation to microgrid to balance generation-load demand when RES-DG + storage devices provide inadequate or surplus power. When power generation exceeds load demand, electricity is transmitted to the substation, resulting in a negative SBDI. The SBDI is defined as follows:

$$SBDI = \left(\sum_{i=1}^{n_{dg}} P_{dg_i(w,s,mt)} \pm P_{SD_i} - \sum_{i=1}^{nb} P_{Li} \right) / \sum_{i=1}^{nb} P_{Li} \qquad (43)$$

Higher the index means microgrid needs more power from main grid. Lower value of index means microgrid need less power from main grid. The negative SBDI has been obtained during low load and high generation of natural resources shows microgrid supply power to main grid. The power can be balanced by managing control variables. These variables be predefined using this proposed algorithm.

Q.10

Other motivation was the impact of combined DG installation not being extensively researched. Can author comment on the impact of this aspect on the siting and sizing problem, if any?

ANS:

Here impact of both solar unit and wind unit generation taken together as per their availability. It shows its impact when two or three nodes are equally loaded. So siting of DG at far end causes reduced grid losses when system is at peak load. but it will causes revers flow of current during light load and high DG generation. If arrangement of switch over of DG possible it will show notable impact on microgrid.

Q.11

What were the factors defining author's choice of PSO and its derivatives in solving various optimization problems for the purpose of this thesis?

ANS:

The nature of developed optimisation problem is non linear, multiobjective and complex. PSO is more effective, less computational and optimistic method to solve this type of problem

Q.12

What was the motivation for not choosing a practical Gujarat or Indian power system data for the purpose of this research?

ANS:

In Gujarat or Indian power system,the microgrid concept is under developing stage. The actual and official data collection would have been tedious process.

Q.1

How Weibull factors k and c are calculated or estimated in your work?
ANS:
The two parameters of Weibull pdf have been applied to modeling the random behaviour of wind speed. The empirical method, which is the case of the moment method, has been used to estimate Weibull pdf parameters to fit available wind speed distribution.
The shape parameter (k) and scale parameter (c) are estimated based on mean wind speed and the standard deviation of wind speed for the specified time laps. The mean wind speed - (v_m) m/s^2 and the standard deviation (v_{sd}) of specified time laps are considered based on historical meteorological data The Weibull probability distribution function of wind speed is characterised by the below equation: ([1],[5], [12]; $c = \left(\frac{v_m}{\left(\Gamma(1+\frac{1}{k}\right)} \right)$

$k = \left(\frac{v_{sd}}{v_m} \right)^{-1.089}$

The fixed value of k has been considered using meteorological data at seashore near Bhavanagar, Gujarat.

Q.2

This thesis has been submitted in year 2022, why researcher taken old data, why don't you consider the latest data i.e. during the year 2021-2022?

ANS:

The work has been started from 2017-2018, So tried to get real data form meteorological department, Ahmedabad,Gujarat for last three year data. They provided the data from 2015 to 2017. It was taken six months. The data are of 3 hours interval. The data of same location has been obtained from the site[www.worldweatheronline.com/lang/en-in-Khambhat-weat gujarat/in.aspx] and (http://niwe.res.in). Analysis has been done for same data.

Q.3

What are the four states of hourly solar irradiation in the proposed solar power generation model? Why this division is needed?

When determining the size and allocation of solar panels, the assumption of beta parameters may lead to an increase in error in power estimation. The modeling of the uncertain nature of solar irradiation and estimation of solar power should necessitate detailed analysis for any location. Based on careful examination of the quarterly solar irradiation statistics and hourly beta pdf for the selected location, it is determined that the variation in the shape of the Beta pdf from quarter to quarter and hour to hour is very large. To reduce the error in calculating probable solar power, state-wise probability of solar power using best fitted hourly beta pdf(beta parameters) of solar radiation is being considered. where,

Table: Solar irradiation state

state	s_1	s_2
1	$s_m - 2(s_{sd})$	$s_m - (s_{sd})$
2	$s_m - (s_{sd})$	s_m
3	s_m	$s_m + (s_{sd})$
4	$s_m + (s_{sd})$	$s_m + 2(s_{sd})$

s_1 and s_2 is lower limit and upper limit of solar irradiation state respectively. s_{mst} is average solar irradiation of the state.

Q.4

This chapter contains details on various pilot microgrid activities taking place in the United States and Europe. Why the researchers has not been considered Indian scenario in this study?

ANS:

The details on various pilot microgrid activities taking place in the United States and Europe has been referred for study purpose. To do work in Gujarat power sector scenario, The analysis of natural resources has been done for seashore of cambay which is in Gujarat; but before applying it on real system,it was felt that it is necessary to prove on existing referred system. The microgrid concept is in developing stage in India.

Q.5

In equation no. 4.1 & 4.2, what is ‘r’ and ‘x’?
ANS:

$$P_{n-1} = P_n + r_{(n,n-1)} \left(\frac{P_n^2 + Q_n^2}{V_n^2} \right) \tag{44}$$

$$Q_{n-1} = Q_n + x_{(n,n-1)} \left(\frac{P_n^2 + Q_n^2}{V_n^2} \right) \tag{45}$$

‘r’= line resistanc/unit and ‘x’= line reactance/unit

Q.6

In this chapter, power flow of a radial distributed system has been solved by the backward-forward sweep method, why it can be not solved by Newton-Raphson method?

ANS:

The backward-forward sweep method is more convenient than NR method for distribution system.

Q.7

Equation nos. 4.11 to 4.13, is it derived yourself or taken reference from literature?

ANS:

Equation nos.4.11

$$G_{loss} = \sum_{ij=1}^{n_b} I_{ij}^2 r_{ij} \quad where, I_{ij} = I_{b(k,k+1)} \tag{46}$$

It is also standard equation for line losses.

Equation nos. 4.12 and 4.13

$$OF_1 = \sum_{ij=1}^{n_t} N_{loss}^t \tag{47}$$

$$OF_2 = DF^t = \frac{\frac{s_p}{P_D}(t)}{\sum_{ij=1}^{n_d} \frac{P_{npdg_i} + P_{mt_i}}{P_D}} * 100 \tag{48}$$

Q.8

What is the difference between PSO and levy distribution? How both are combined in your work?
ANS:

Table: Difference between PSO and Levy PSO

PSO	Levy PSO
In standard/convectional PSO, randomisation of particles follows uniform distribution	In levy PSO , particles movement is replaced by Levy flight, i.e particles update rule follows levy distribution.
The PSO is popular because of its simplicity and intuitive interpretation of particle behavior in search space and its relatively good efficiency, which unfortunately decreases with the increasing problem dimensionality.	The levy flight improved better search space exploration for multi dimension problem.
The convergence rate is controlled by manipulating the inertia and individual and social influence coefficients in the swarm in the algorithm.	here inertia weight is set as random variable, which follows Levy flight distribution: $$w_t \sim Levy_{pdf}(w, \mu, \beta)$$

The PSO combined with Levy flight (LFPSO) to overcome the PSO algorithm is being trapped in local minima. Levy gives faster converges to obtained optimum value of multi functional problem.

Q.9

What is negative SBDI?

ANS:

In this research work term SBDI means substation dependency index; It is defined as an index that reflects the amount of power exchanged from substation to microgrid to balance generation-load demand when RES-DG + storage devices provide inadequate or surplus power. When power generation exceeds load demand, electricity is transmitted to the substation, resulting in a negative SBDI. The SBDI is formulated as follows:

$$SBDI = \left(\sum_{i=1}^{n_{dg}} P_{dg_i(w,s,mt)} \pm P_{SD_i} - \sum_{i=1}^{nb} P_{Li} \right) / \sum_{i=1}^{nb} P_{Li} \qquad (49)$$

Q.10

Why you have considered Energy storage device operation constraint in objective function given in chapter 5?

ANS:

The main purpose of energy storage devices is to balance generation and consumption of the microgrid, to minimise the transfer of power from subgrid and to lower substation dependency index. The operation and maintenance cost of energy storage devices are influenced by the device's strategy and charging discharging frequency. To avoid frequent switching, it is expected that storage devices are permitted to function within maximum charging and discharging limits. In this work,capacity of storage device is considered 30% of DG capacity. for any scenario if load $\leq$ generation at specific node, storage device will charge during that hour, when it reaches maximum charging limits, it will supply to other node. So the cost of charging-discharging is considered as operational constraints.

Q.11

In this chapter, IEEE-13 node Distribution System considered as Microgrid but to apply levy flight PSO algorithm you have discussed Steps to Solve Optimization Problem Using LF-PSO for 12-node Grid connected Microgrid. Why?

The IEEE -13 node radial distribution system has been used as a microgrid for the implementation of the proposed method. The transformer between node 633 and node 634 is considered as a unity gain isolated transformer. Node 634 is loaded and these is no load on node 633. Both nodes are combined as one node. So it is 12 node system.

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Thank you

List of Publication

List of Paper Presented at Conferences

1. P. Upadhyay and S. Joshi, “Optimal summation of natural power distributed resources in grid connected microgrid,” in 2019 International Conference on Information Technology (ICIT). IEEE, 2019, pp. 400–405..
2. P. A. Upadhyay and S. K. Joshi, "Models and methods for integrating green power distributed generators in microgrid," 2017 52nd International Universities Power Engineering Conference (UPEC), 2017, pp. 1-6, doi: 10.1109/UPEC.2017.823195

List of Paper published in Journal

1. Upadhyay Parul, and Satish Joshi. (2020) '"Computation of Power Generation of Green Power Unit based on Probability Distribution Parameter." International Journal of Recent Technology and Engineering (IJRTE), 4447-4452. doi:10.35940/ijrte.E6677.038620 .

List of Paper Submitted to the Reputed Journals (Under Review)

1. Upadhyay Parul, Joshi S.K. Integration of Natural Power Resources combined with Energy storage device in Microgrid, Journal of The Institution of Engineers (India): Series B.