Random furrowing for a stochastic unit commitment solution

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Abstract: - The Unit Commitment Problem involves the inherent difficulty of obtaining optimal combinatorial power generation schedules over a future short term period. The formulation of the generalized Unit Commitment Schedule formulation involves the specific combination of generation units at several de-rated capacities during each hour of the planning horizon, the load demand profile, load indeterminateness and several other operating constraints. This largely deterministic schedule continues to find favor with several plant operators, keeping in mind the close operating time-periods involved. However, the deterministic nature of the load profile is sought to be phased out by a stochastic pattern that is realistic and mirrors real-life situations, owing to modern trends in Demand side management. This shift is in tune with the ongoing power restructuring activities of electricity power reforms. The stochastic profile is obtained by a suitably tuned 2-parameter Weibull distribution that uses appropriate shape and scale parameters. The resulting band of generated load profiles are used to evaluate net power and penal costs associated with a set of pervasive randomized probability indices. The exact UCS comprises of a specific unit absolute state corresponding to a certain time period within the planning horizon. Subsequently, regression analysis is applied to establish the correlation between the absolute states and the cumulative randomized load demand against the intervals within the planning horizon. This method is analogous to random furrowing of probabilistic demand profile.

Key-Words: Heuristic, stochastic load pattern, Polynomial regression, Power restructuring, Probabilistic demand profile, Statistical quotients, Random furrowing, Unit Commitment schedule, Weibull distribution

Received: June 14, 2022. Revised: August 16, 2023. Accepted: September 28, 2023. Published: November 6, 2023.

1. Introduction

The Unit Commitment Problem (UCP) in a micro-level power system involves the determination of start-up and shut-down schedule of units within a generating block, to meet the forecasted demand over a future short term period. The unit commitment decision involves the specific combination of units at corresponding de-rated capacities during each hour of the planning horizon, considering system capacity requirements, load demand indeterminateness and several other constraints. The constraints that are inherent to a micro power system include probabilistic fluctuations and random nature of load profiles within each cycle. This is due to the fact that randomness, inaccurate load forecasts and probabilistic distribution function assignations suffer from the inherent volatile nature of demand and.

The related Unit Commitment Schedules (UCS) involves the allocation of system demand and spinning reserve capacity among the operating units for each specific hour of operation. The minimization objective is to obtain an overall least cost solution for operating the power system over the scheduling horizon. The UCP belongs to the class of complex combinatorial optimization problems, involving both integer and continuous variables. Solutions for realistic situations have generally defied application of rigorous techniques [1,2].

Over the years, there has been considerable shift from a deterministic hourly load formulation towards a stochastic one [1]. A case in point is the adoption of hourly demand by a multi-variate normal distribution approximation. Caprices of nature, power swings and local switching contribute to the aggravation of the problem. The said factors cause chaos in the ordering of the demand. Hence it is pertinent to extract a semblance of order from the very random nature of the demand. The proposed method uses the concept of absolute states and cumulative random demand to determine efficient UCS[3].

2. Problem Statement

The overall objective function of the UCPs of N generating units for a scheduling time horizon T is given by [3].

$$\text{Min} \sum_{i=1}^{N} \sum_{t=1}^{T} [U_{it} F_{it}(P_{it}) + V_{it} S_{it}] \qquad (1)$$

Where, i = Unit i, t = time period,

U_{it} = Unit status (1 or 0)

P_{it} = Output power of unit i at time t.

$F_{it}(P_{it})$ = Operation cost of committed unit i,

$$F_{it}(P_{it}) = a_i P_{it}^2 + b_i P_{it} + c_i \qquad (2)$$

V_{it} = Start-up/shut-down variable

S_{it} = Start-up/shutdown variable (fn. of the down time of unit i)

PD_t = System peak demand (MW) at t subject to constraints.

(a) Load demand constraints:

$$\sum_{i}^{N} U_{it} P_{it} = PD_t \qquad (3)$$

(b) Spinning reserve:

Spinning reserve, R_t is the total amount of generation capacity specified by the system operator from all synchronized units to meet any variation in operating conditions.

$$\sum_{i}^{N} U_{it} P_{max,i} \gg (PD_t + R_t) \qquad (4)$$

R_t is obtained by an initial deterministic percentage of PD_t at the t^{th} hour, followed up with random values subsequently.

(c) Generation limits

$$U_{it} P_{min,i} \ll P_{it} \ll U_{it} P_{max,j} \qquad (5)$$

where $P_{min,i}$ and $P_{max,i}$ are the extreme generation limits of unit i. Besides, there are secondary constraints relating to minimum up/down time, unit initial status, crew constraints, maintenance issues, etc.

3. Proposed method – Random furrowing

The Unit Commitment Problem (UCP) has thrown up several solution methods [4,5]. The authors have developed a random furrowing technique to generate a generic solution. This method attempts to graft random variables into the generating block and the demand data, and thus obtain an acceptable UCS.

The modified representation of a generation block is represented in Table-1. Normally, each unit is characterized by a nominal power rating which has a 2-state operation (Up and Down). In such a case, the maximum and minimum power ratings merely serve as limit constraints. By themselves, they do not form power states. This shortcoming is addressed while considering a micro-level power system, which consists of a fewer number of units; each, assuming a relatively larger number of de-rated states [4].

Table 1: Generic data for generation

1	2	3	4	5	6	7	8
Unit	Nom. Rating	Power limits		Intervals	Cost coeff.		
		P min	P max		a	b	c
	← (MW) →						
1	P_1	P_{min1}	P_{max1}	k_1	a_1	b_1	c_1
2	P_2	P_{min2}	P_{max2}	k_2	a_2	b_2	c_2
3	P_3	P_{min3}	P_{max3}	k_3	a_3	b_3	c_3
.	.	.	.	.	.	.	.
n	P_n	P_{minn}	P_{maxn}	k_n	a_n	b_n	c_n

$$P_{min\,i} \le P_i \le P_{max\,i} \quad for\ i = 1 \ldots\ldots N \qquad (6)$$

Using an appropriate interval value k_i (Column5), P_{it} is made to swing between $P_{min\,i}$ and $P_{max\,i}$ for the i_{th} unit in the t^{th} interval.

Hence, P_{it} assumes all states between $P_{\min i}$ and $P_{\max i}$, thereby overlapping its nominal rating. The corresponding large number of de-rated power states in such a power system are often much more that in a middle-order power system with a larger number of generating units [7].

The power states are termed as i) Absolute states and ii) Period states. The number of period states is determined by the combinatorial function

$$\boldsymbol{S_p} = [(\boldsymbol{k_1}+\mathbf{2})\boldsymbol{C_1} \times (\boldsymbol{k_2}+\mathbf{2})\boldsymbol{C_1} \times (\boldsymbol{k_3}+\mathbf{2})\boldsymbol{C_1} \dots\dots\dots \times (\boldsymbol{k_n}+\mathbf{2})\boldsymbol{C_1}] - \mathbf{1} \quad (\mathbf{7})$$

For instance $(k_1+2)C_1$ represents an ${}^nC_r$ function. The number of absolute states is defined by

$$\boldsymbol{S_a} = \boldsymbol{S_p t} \quad (\mathbf{8})$$

where $k_1, k_2, k_3, \dots\dots\dots k_n$ are listed earlier
t=time period in the planning horizon. (Here, 24 Hours)

The introduction of the interval factor k serves 2 main objectives.

a) The ramping constraint is obviated.
b) A multiplicity of de-rated power states is created for each unit, thereby introducing a localized multi-state operation.
c) Recognizing that the hourly demands are stochastic quantities, the absolute states conform to a random set of variables with a high degree of probability.

The demand is qualified with the aid of suitable random parameters introduced in Table-2.

Table 2: Demand profiles

1	2	3	4	5	6	7	8
Hr.	Dem (MW)	Fluct. (%)	Rand var. (0-1)	Cum. Rand var.	Eff. demand with fluctuation (MW)	Eff. demand with randomness (MW)	Cum. demand with randomness (MW)
1	d_1	f_1	r_1	r_1	$ef_1 = d_1\times(1+(f_1/100)$	$er_1=ef_1\times r_1$	$cr_1=er_1$
2	d_2	f_2	r_2	$r_1 + r_2$	$ef_2 = d_2\times(1+(f_2/100)$	$er_2=ef_2\times r_2$	$cr_2 =cr_1+er_2$
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
24	d_{24}	f_{24}	r_{24}	$r_{23}+r_{24}$	ef_{24}	er_{24}	cr_{24}

Columns 1 and 2 are standard entries obtained by regression or experience.

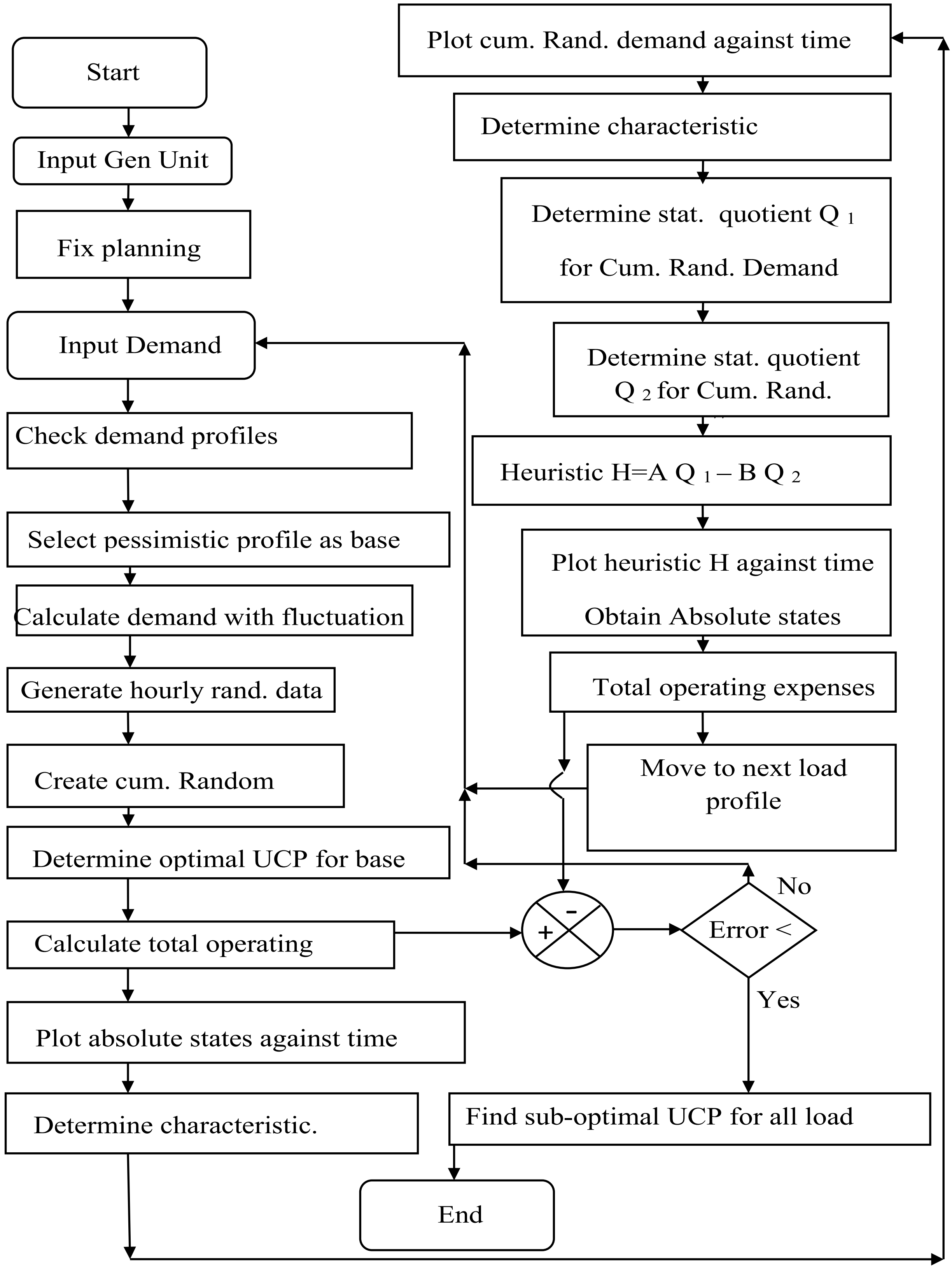
Column 3 is a measure of the spinning reserve, as a % of Column-2. In this case, it creates an escalation factor.

Column-4 is obtained from a random generator.

Columns 5 to 8 are subsequently determined to enhance the variables.

The earlier tables along with Equations(1-8) are used to generate the trial solution using a MATLAB script file. A Unit commitment schedule has been prepared for the Case study. It includes a specific condition (Column 11). When the generation is short of the demand, condition-1 is in place. In the reverse case, penal power and penal costs are calculated, giving rise to Condition-2. The detailed method is amplified in Fig.1.

Fig.1: Proposed algorithm



The crux of the method is dependent on the following plots

a) Hourly interval Vs. Absolute state (t Vs. Sa_i)
b) Hourly interval Vs. Cumulative random demand (t Vs. cr_i)

4. Case study

Consider a generating block, which is representative of an Independent power producer whose base details are specified in Table 3.

Table 3: Typical generating block data

1	2	3	4	5	6	7	8
Unit	Nom. Rating (MW)	P_{min} (MW)	P_{max} (MW)	Intervals	a	b	c
1	10	5	10	7	0.75	1.20	100.00
2	20	6	20	8	1.25	0.60	123.00
3	30	10	35	9	0.90	0.50	204.00

Column-3 represents the % fluctuation in load demand, which is designed to escalate the. demand. The swing on the lower side is not considered.

To illustrate, the 7 stages for Unit-1stretch from 5 to 10 MW.
Column 5 represents the number of intervals k_i between P_{min} and P_{max}. These determine the de-rated power states as indicated in Table 4.
Columns 6, 7 & 8 correspond to the terms in Equation (2).

The load demand is projected on a 24 hour basis in Table 5.

For instance, at the 20th hour, the demand is likely to be (44×1.05= 46.2 MW). Column-4 represents a series of random numbers generated from either MATLAB or Excel. Table-5 is enhanced to create a modified demand as detailed in Table 6.

Table-4. De-rated power states (MW)

Unit-1	0	5.00	5.71	6.43	7.14	7.86	8.57	9.29	10.00		
Unit-2	0	6.00	7.75	9.50	11.25	13.00	14.75	16.50	18.25	20.00	
Unit-3	0	10.00	12.78	15.56	18.33	21.11	23.89	26.67	29.44	32.22	35.00

Table 5. Load demand data

1	2	3	4	1	2	3	4
Hour	Demand (MW)	Fluct. (%)	Rand	Hour	Demand (MW)	Feluct. (%)	Rand
1	10	2	0.7119	13	30	4	0.2139
2	10	3	0.9450	14	28	4	0.4182
3	10	3	0.2922	15	35	3	0.0711
4	11	3	0.6137	16	55	4	0.1209
5	15	4	0.0003	17	35	3	0.6105
6	20	5	0.1567	18	36	3	0.6858
7	26	5	0.4863	19	40	4	0.2576
8	27	4	0.0980	20	44	5	0.5343
9	50	3	0.2860	21	43	7	0.4205
10	31	6	0.0413	22	20	6	0.2588
11	32	6	0.1775	23	13	3	0.5793
12	32	5	0.6418	24	9	2	0.7996

To illustrate, the 7 stages for Unit-1 stretch from 5 to 10 MW.
The load demand is projected on a 24 hour basis in Table 5.

Column-3 represents the % fluctuation in load demand, which is designed to escalate the demand. The swing on the lower side is not considered. For instance, at the 20th hour, the demand is likely to be (44×1.05= 46.2 MW). Column-4 represents a series of random

numbers generated from either MATLAB or Excel. Table-5 is enhanced to create a modified demand as detailed in Table 6. [5]

Table-6.: Modified Demand data

1	2	3	4	5	6	7	8	9
Hr.	Dem	Fluct.	Rand.	Cum. Rand	Dem with fluc.	Cum.dem with fluc.	Fluc. dem with rand.	Cum.fluc dem with rand.
	MW	%			← MW →			
1	10	2	0.711	0.7119	10.20	10.20	7.26	7.26
2	10	3	0.945	1.6569	10.30	20.50	9.73	17.00
3	10	3	0.292	1.9491	10.30	30.80	3.01	20.01
4	11	3	0.613	2.5629	11.33	42.13	6.95	26.96
5	15	4	0.000	2.5632	15.60	57.73	0.00	26.96
6	20	5	0.156	2.7199	21.00	78.73	3.29	30.26
7	26	5	0.486	3.2063	27.30	106.03	13.28	43.53
8	27	4	0.098	3.3043	28.08	134.11	2.75	46.29
9	50	3	0.286	3.5904	51.50	185.61	14.73	61.02
10	31	6	0.041	3.6317	32.86	218.47	1.36	62.38
11	32	6	0.177	3.8092	33.92	252.39	6.02	68.40
12	32	5	0.641	4.4511	33.60	285.99	21.57	89.96
13	30	4	0.213	4.6650	31.20	317.19	6.67	96.64
14	28	4	0.418	5.0833	29.12	346.31	12.18	108.82
15	35	3	0.071	5.1545	36.05	382.36	2.57	111.38
16	55	4	0.120	5.2754	57.20	439.56	6.92	118.30
17	35	3	0.610	5.8859	36.05	475.61	22.01	140.31
18	36	3	0.685	6.5718	37.08	512.69	25.43	165.74
19	40	4	0.257	6.8294	41.60	554.29	10.72	176.46
20	44	5	0.534	7.3637	46.20	600.49	24.68	201.14
21	43	7	0.420	7.7843	46.01	646.50	19.35	220.49
22	20	6	0.258	8.0431	21.20	667.70	5.49	225.98
23	13	3	0.579	8.6225	13.39	681.09	7.76	233.74
24	9	2	0.799	9.4221	9.18	690.27	7.34	241.08
ū			0.392	4.7858			10.04	105.84
σ n-1			0.264	2.3647			7.57	77.31

The mechanism for generating Table 6 follows the pattern elucidated earlier. Based on the cost coefficients, the generating costs of the 3 units have been calculated and summarized in Table-7.

Table 7: Costs (INR) at de-rated power states

Unit\State	1	2	3	4	5	6	7	8	9	10	11
1	100	125	131	139	147	156	165	176	187		
2	123	172	203	242	288	342	404	473	550	635	
3	204	299	357	430	516	616	730	857	999	1155	1324

To cite an example, considering Unit-1,the operational cost of running Unit-2 at 6 MW is INR.172. State generation was achieved by a program coded in MATLAB.

The complete enumeration gives rise to 23736 states. For brevity, a certain part of the state listing is reproduced in Table 8.

Table 8: State enumeration

1	2	3	4	5	6	7	8
Period	Abs State	Period state	Unit state				
			U-1	U-2	U-3	Net cost	Cond
						INR	
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
1	988	988	9	10	10	460.89	1
1	989	989	9	10	11	491.68	1
2	990	1	1	1	2	522.00	2
2	991	2	1	1	3	146.57	1
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
24	23735	988	9	10	10	418.46	1
24	23736	989	9	10	11	446.23	1

Since this table is vital for further progress, a summary is in order.

Col.1 ~ Time period T (Hourly basis 1, 2, …… , 24)

Col.2 Absolute state number (Across all time periods)

Col.3 ~ Unit wise state number (Across a particular time-period

The number of states within a particular time-period, as represented inCol.2 should have been different, owing to the generally differing values of intervals k. However, these have been made equal (In this specific case ~ 989), by considering null entities.

Col.4,5& 6 ~ Specific de-rated power states of Unit Nos. 1,2 & 3.For instance, absolute state number 23735 denotes Unit State-988at the 24rdhour, wherein State-9 of Unit-1 (10 MW), State-10 of Unit-2 (20 MW) and State-10of Unit-3 (32.22 MW) are considered.

Col.7 ~ This forms the net cost, taking into account the operational and penal cost. Penal power is presumptive of the generated power that is not utilized.

Col.8 ~ Indicates a specific condition. 1~Spinning reserve 2~None

5. Results

The Unit Commitment schedule (UCS) is prepared by indexing the unabridged Table-8 at 2 levels. The first level is on the basis of the time period. The second level indexes the net operational cost (Col.7). The complete UCS is listed in Table 9.

Table 9: Unit Commitment Schedule (UCS)

1	2	3	4	5	6	7	8
Hour	Abs. state	Period state	State			Gen.	Op. Cost
			U-1	U-2	U-3		
(Hr.)						(MW)	(INR)
1	121	121	2	2	1	11	72.31
2	1110	121	2	2	1	11	72.48
3	2099	121	2	2	1	11	72.48
4	3198	231	3	2	1	11.71	79.53
5	4177	221	3	1	2	15.71	126.25
6	5177	232	3	2	2	21.71	174.27
7	6837	903	9	3	2	27.75	261.31
8	7816	893	9	2	3	28.78	288.24
9	8886	974	9	9	7	52.14	1039.26
10	9806	905	9	3	4	33.31	391.89
11	10816	926	9	5	3	34.03	405.2
12	11805	926	9	5	3	34.03	404.91
13	12793	925	9	5	2	31.25	346.91
14	13771	914	9	4	2	29.5	300.17
15	14663	817	8	5	4	36.09	466.29
16	15811	976	9	9	9	57.69	1308.86
17	16641	817	8	5	4	36.09	466.29
18	17620	807	8	4	5	37.12	505.96
19	18621	819	8	5	6	41.65	652.4
20	19763	972	9	9	5	46.58	825.63
21	20611	831	8	6	7	46.17	820.3
22	21001	232	3	2	2	21.71	174.49
23	22319	561	6	2	1	13.86	103.79
24	22868	121	2	2	1	11	70.02

This particular UCS is sought to be characterized by the average operational cost over 24 hours.. The next step is to modify the UCS to make it more amenable to generalization. The algorithm specified in Fig.1 is used to generate trial solutions. The pessimistic (highest load profile) has been selected as the base profile.10 trials were considered, the last being the most optimistic load profile. [6]

Table. 10. Load demand statistics

1	2	3	4	5	6	7	
Case		Rand	Cum Rand	Rand Dem	Cum Rand Dem	Multiplier (ū/ σ n-1)	
Base	ū	0.393	4.786	10.045	105.837	1.369	Col.6
	σ n-1	0.265	2.365	7.574	77.311	2.024	Col.4
Trial-1	ū	0.483	6.526	14.623	169.807	1.445	-do-
	σ n-1	0.327	3.270	12.536	117.507	1.996	
Trial-2	ū	0.547	6.506	19.378	206.702	1.303	-do-

	σ n-1	0.276	4.000	14.267	158.650	1.627	
Trial-3	ū	0.557	6.881	20.560	236.961	1.362	-do-
	σ n-1	0.263	4.195	14.649	174.029	1.640	
Trial-4	ū	0.515	6.830	20.162	238.579	1.454	-do-
	σ n-1	0.265	3.792	14.826	164.085	1.801	
Trial-5	ū	0.522	6.837	21.186	261.693	1.465	-do-
	σ n-1	0.275	3.966	14.919	178.627	1.724	
Trial-6	ū	0.618	7.772	26.281	302.907	1.426	-do-
	σ n-1	0.337	4.449	18.145	212.439	1.747	
Trial-7	ū	0.568	6.483	25.362	268.186	1.346	-do-
	σ n-1	0.272	4.066	16.120	199.263	1.594	
Trial-8	ū	0.451	5.489	20.240	231.694	1.442	-do-
	σ n-1	0.343	3.187	17.003	160.725	1.723	
Trial-9	ū	0.375	3.989	19.183	190.930	1.232	-do-
	σ n-1	0.266	2.880	15.866	154.955	1.385	
Trial-10	ū	0.399	5.309	18.630	229.644	1.705	-do-
	σ n-1	0.305	2.631	13.674	134.689	2.018	

Table 11. Load trials

1	2	3	4	5	6	7	8
Case	Multip.	Coefficients					Remarks
	(ū/ σ n-1)	p1	p2	p3	p4	p5	
Base	1.369	0.01	-0.65	7.05	1066.0	-1064.5	Abs State
	2.024	0.00	0.12	-1.42	11.61	-3.91	Cum Ran Dem
		0.02	-1.13	12.52	1435.8	-1449.3	Final fit
Trial-1	1.445	-0.02	0.92	-15.28	1149.6	-894.8	-do-
	1.996	0.00	0.09	-0.63	10.50	-0.6	
		-0.03	1.15	-20.82	1640.3	-1291.9	
Trial-2	1.303	0.02	-1.16	21.96	877.2	-272.5	-do-
	1.627	0.00	0.11	-0.71	13.1	-14.9	
		0.03	-1.68	29.77	1121.6	-330.8	
Trial-3	1.362	-0.03	1.57	-27.78	1226.7	-965.0	-do-
	1.64	0.00	-0.08	3.08	-8.90	16.7	
		-0.05	2.28	-42.88	1684.8	-1341.3	
Trial-4	1.454	0.00	-0.18	4.91	991.07	-414.2	-do-
	1.801	0.00	-0.12	3.10	-5.89	19.4	
		0.00	-0.05	1.54	1451.6	-637.3	
Trial-5	1.465	-0.04	1.99	-38.12	1342.6	-1399.7	-do-
	1.724	0.00	-0.18	4.38	-11.15	19.2	
		-0.06	3.23	-63.39	1986.1	-2083.8	
Trial-6	1.426	-0.04	2.14	-37.72	1280.2	-945.1	-do-
	1.747	0.00	0.12	0.02	10.2	10.9	
		-0.06	2.86	-53.83	1807.5	-1366.7	
Trial-7	1.346	-0.03	1.32	-23.14	1157.1	-480.2	-do-

	1.594	0.00	0.21	-2.40	26.38	-23.9	
		-0.03	1.45	-27.31	1515.2	-608.2	
Trial-8	1.442	-0.01	0.37	-7.47	1059.0	-304.0	-do-
	1.723	0.00	0.04	1.00	0.67	23.7	
		-0.01	0.46	-12.50	1525.4	-479.1	
Trial-9	1.232	0.00	0.02	-1.54	1025.4	-263.7	-do-
	1.385	0.00	0.06	-0.13	8.17	-8.03	
		0.00	-0.06	-1.72	1252.1	-313.9	
Trial-10	1.705	-0.02	1.12	-19.22	1121.4	-344.1	-do-
	2.018	0.00	-0.08	1.03	15.15	-7.2	
		-0.04	2.06	-34.84	1881.4	-572.1	

For the base profile
Q_1 = Col.6 ratio = (105.837/77.311) = 1.369 and
Q_2 = Col.4 ratio = (4.786/2.365) = 2.024 and so on for all 10 trials.
Characteristic regression factors A, B are determined from Table 11.
Considering the base case, $Q_1 \equiv 1.369$, $Q_2 \equiv 2.024$
The absolute space regression polynomial is given by

$$S_a = 0.01t^4 - 0.65t^3 + 7.05t^2 + 1066t + 1064 \qquad (9)$$

.

The cumulative random demand variable is extrapolated to

$$C_{r\,base} = 0.12t^3 - 1.42t^2 + 11.61t - 3.91 \qquad (10)$$

The effective fit is determined by the heuristic

$$S_{ac} = H = AQ_1 - BQ_2 \qquad (11)$$

$$S_{ac} = 0.02t^4 - 1.13t^3 + 12.52t^2 + 1435.84t - 1449.38 \qquad (12)$$

Such characteristic equations are developed for 10 trials, the results of which are enumerated in Table 2. This is plotted for the base profile in Fig.2

Fig.2: Plot of heuristic

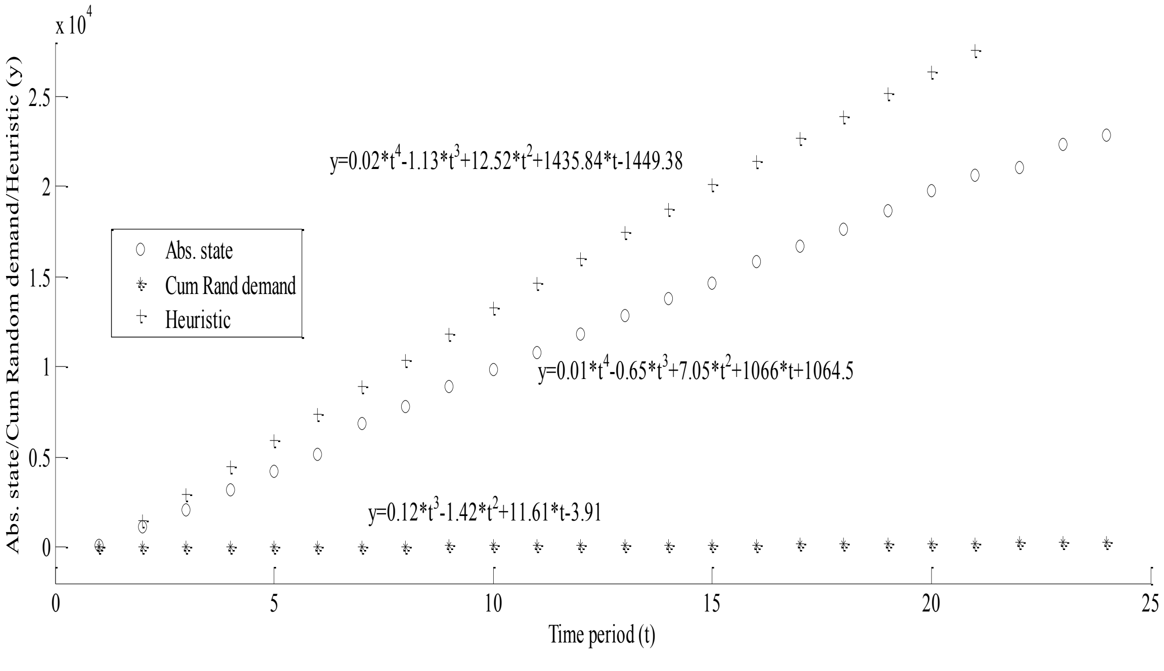


Table 12, being calculated for 11 trials, has been pruned to display the first 3 trials only.

The underlined entries indicate that the calculated absolute space identifier have exceeded the upper ceiling (23736 for the specified Case study). In addition, some negative values have been generated.These are potential errors which need to be addressed at alater stage. Space contraints dictate the non-inclusion of individual cost figures in Table 12. However, the total operating costs for each trial have been indicated.

Table 12 has been summarized in Table 13, indicating the excess bound cases and the operating cost error. The error is the maximum for the base profile, tailing off to acceptable values for optimistic load profiles, indicating the efficacy of the proposed method.

Table 12:Application of heuristic to determine absolute states

Hour	Base		Trial-1		Trial-2		Trial-3	
	Actual	Calc	Actual	Calc	Actual	Calc	Actual	Calc
1	121	-2	341	329	671	819	331	303
2	1110	1464	1330	1914	1660	2019	1430	1874
3	2099	2942	2319	3470	2649	3259	2419	3385
4	3198	4427	3528	5002	3188	4532	3518	4846
5	4177	5914	4507	6514	4078	5829	4298	6267
6	5177	7398	5397	8011	5727	7143	5848	7657
7	6837	8875	6848	9494	6739	8469	6860	9022
8	7816	10340	7827	10967	7838	9800	7729	10370
9	8886	11792	8897	12431	8877	11131	8888	11706
10	9806	13226	9817	13888	9708	12457	9829	13034
11	10816	14640	10707	15337	10828	13776	10839	14357
12	11805	16033	11816	16778	11796	15083	11828	15677
13	12793	17403	12773	18211	12575	16376	12785	16995
14	13771	18749	13782	19633	13762	17654	13564	18310
15	14663	20070	14784	21043	14795	18915	14775	19621
16	15811	21367	15822	22437	15713	20159	15604	20926
17	16641	22639	16762	23810	16773	21386	16753	22220
18	17620	23887	17741	25160	17752	22596	17643	23499
19	18621	25113	18742	26481	18753	23792	18644	24757
20	19763	26318	19743	27766	19634	24975	19755	25988
21	20611	27504	20732	29009	20743	26149	20634	27182
22	21001	28675	21331	30204	21661	27316	21672	28331
23	22319	29833	21979	31342	22309	28482	21880	29424
24	22868	30981	22978	32415	23308	29650	22968	30450
Cost	19686	24592	20726	27284	22025	24048	23458	23681
% Error		25		32		10		1

Table 13. Summary of heuristic application

		←Trials→									
	Base	1	2	3	4	5	6	7	8	9	10
States in excess of bounds (Max-24)	7	8	6	6	8	8	7	6	7	5	10
% Error	25	32	10	1	3	3	9	11	20	21	8

6. Conclusion

The paper proposes a new method to generate generalized sub-optimal Unit Commitment schedules. This is effective in micro-level power systems which are characterized by a few units possessing relatively large number of de-rated states. In such situations, the method tackles probabilistic demand by introducing a measure of randomness in the load profile. The load profile is categorized into a spectrum varying from the pessimistic to the optimistic. For each profile, a set of random numbers are generated, from which the cumulative randomized demand values are obtained. The pessimistic profile is chosen as the base, for which a pair of statistical quotients are determined. Further, enumeration is carried out to determine a base Unit Commitment schedule, which generates a set of absolute state identifiers. The identifiers and cumulative randomized demand values are plotted against the periods in the planning horizon, yielding 4th degree polynomial regression characteristics. These characteristics are fused with the statistical quotients to yield a trial heuristic. When expanded over the planning horizon, the heuristic calculates a new set of Unit Commitment schedules. This is tested over the entire load spectrum.

A case study for a 3-unit system with multiple de-rated states has been used to simulate the proposed method. It has also been tested on a spectrum of 10 load profiles with a fair degree of success. The 2 main drawbacks pertain to the solution state identifiers overstepping the state limits, and the error quantum. These are proposed to be tackled in future work. Nevertheless, at this stage, the proposed method shows a lot of promise in achieving a robust, sub-optimal Unit Commitment schedule. [7]

References

[1] J.Endrenyi, *Reliability Modeling in Electric Power Systems*, New York, USA, John Wiley and Sons, 1978.

[2] Alberto Leon Garcia, *Probability and Random Processes for Electrical Engineering*, 2nd ed. New York, USA: Pearson Education, 1994.

[3] Ce Shang, Teng Lin, A linear reliability evaluated unit-commitment,*IEEE Transactions on Power Systems,* Vol. 37, No. 5, Sept. 2022.

[4] Yiping Yuan, Yao Zhang, Jianxue Wang, Zhou Liu, Zhe Chen, Enhancement in reliability-constrained unit commitment considering state-transition-process and uncertain resources, *IET Generation, Transmission & Distribution*, Vol.15, Issue 24, pp. 3488-3501.

[5] P.C.Thomas, Balakrishnan.P.A, Reliability analysis of smart-grid generation pools, *IEEE 2011 PES Innovative Smart Grid Technologies Conference*; Dec. 2011, Kollam, India.

[6] Menghan Zhang, Zhifang Yang, Wei Lin, Juan Yu, Wenyan Li, Internalization of Reliability Unit Commitment in day-ahead market: Analysis and Interpretation, *Applied Energy*, Vol. 326. Nov. 2022.

[7] Yong Liang, Long He, Xinyu Cao, Zuo-Jun Shen, Stochastic control for smart grid users with flexible demand, *IEEE Trans on Smart Grids*, Vol.4, 2013;pp. 2296-2308.

Contribution of Individual Authors to the Creation of the Scientific Article

P.C.Thomas established the linkage of the phantom unit commitment to the stochastic process. He further set out the algorithm in Fig.1.

Shinosh Mathew was instrumental in developing the MATLAB code necessary for the different load trials.

Bobin K Mathew executed the necessary statistics.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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