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PARTIAL OUTAGE ALONG WITH GAME THEORY ALGORITHM FOR ENERGY COST OPTIMIZATION IN DEVELOPING COUNTRIES

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ABSTRACT
This paper describes the significant cost saving opportunities for consumers in developing coun- tries by the use of a simple non-co-operative game theoretic mathematical model for demand- side-management techniques along with partial outage to mitigate the massive use of diesel back-up during grid outages and also other cost optimization schemes. Application of real time load scheduling optimization is investigated during power outages, for residential consumer in India. This method involves a beautiful formulation of a non–co-operation behavior between the diesel generator & the residen- tial consumer during power outages. This involves a tree model with a two player game, where in player one is the diesel generator & player two is the consumer. Depending on the duration of the outage & the consumers limit on the cost for energy different cost optimization strategies can be generated. The load types modeled include passive loads and schedulable, *i.e.* typically heavy loads. It is found that this DSM schemes show excellent benefits to the consumer. The maximum diesel savings for the consumer due to strategy formulation can be approximately ranging from 45% to as high as 75% for a flat-tariff grid. The study also showed that the actual savings potential de- pends on the timing of power outage, duration and the specific load characteristics.

I. INTRODUCTION
Demand-side-management (DSM) policies are being formulated by various stakeholders in India and other developing countries [1-3]. These policies are specifically targeted to overcome large energy demand-supply gaps, to provide inclusive and reliable power for entire populations. For example, in India, load scheduling has recently been implemented successfully for the agricultural sector. As in developed countries, load scheduling is driven by the utility for peak clipping of demand, load shifting for energy conservation and/or supporting load growth. In this work, our aim is to highlight the urgent need for demand-side-management policies to address one of the major unaddressed challenges for a consumer in a developing country which is the problem of frequent power outages. DSM solutions and policies need to be developed, validated and framed to enable the consumer get reliable power and reduce his dependence on expensive diesel back-up systems.

Tables 1(a) and **(b)** in [4,5] provide power outage data for several major cities in India and in other develop- ing economies such as Africa, Philippines, South America and observe that power outages range from 2 hours to more than

10 hours a day. Power blackouts typically result in total loss of power to large parts of the entire city to large districts. Different scenarios and causes for planned/unplanned power outages in India are described in [4,5]. Due to this grid unreliability, the market for genset and UPS systems is India is worth several billion dollars and growing at a rapid

20% annual rate. In India, residential consumers sometimes pay large premium (~3X) over grid power due to use of expensive back-up systems [4,5]. Service businesses (e.g. photocopier centers, medical diagnostic labs, service apartments, wedding halls etc.) charge higher rates to the consumer during power outages. Home owners association (HOA) in apartment complexes are faced with large diesel bills due to a shared gen-set and these aditional costs are periodically collected from the consumer. In hospitals, the continuous power is ensured by using UPS systems. According to the Bureau of Energy Efficiency in India [6], to deliver a sustained economic

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growth rate of 8% to 9% through 2031-32 and to meet life time energy needs of all citizens, India needs to increase its primary energy supply by 3 to 4 times and electricity generation capacity about 6 times. Based on these aforementioned statistics and the present high inefficiencies in the grid, it is likely that power outages are here to stay unless DSM policies are directly targeted at mitigating the large power outages for all consumers.

II.PARTIAL OUTAGE TECHNIQUE

Due to sever power cuts in India, by knowing the schedule of the power cuts well in advance a lot of smartness can be added to the system to manage the power cuts very effectively, using solar, load shifting technique and partial outage techniques. The first algorithm focuses on obtaining a strategic mathematical model using simple computational intelligence designs to efficiently manage the distribution of power to all areas, while also working to maintain grid stability and utility. The second algorithm highlights the methodology to effectively implement PV strategies that would serve to mitigate the effects of a power outage, initially from the perspective of the consumer. Due to recent advancements in technology, evidence is shown that photovoltaic power generation has the potential to overcome these challenges and can lessen the effects of massive power outages. The 3rd Algorithm highlights the load segregation load shifting: Load Segregation &Categorization : Consumers spend crores of rupees annually only on back-up power. Both diesel as well as inverter-battery as back-up. There is a very crude method of power management in the back-up segment. So it is very important to understand the loads present in the building in order to do fine grain power management on back-up power which is very expensive.

TABLE 1: Table containing the load profile's of all areas

LOAD		Total Sanctioned Load (kW)	Avg Power Consumption at time t (kW)																							
SL NO	AREAS		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	AREA 1	200	97.33	97.69	56.1	96.39	109.2	91.06	64.1	68.4	119.4	127.4	93.37	104.1	103	85.94	116.1	58.16	127.7	122.2	79.81	77.77	93.68	80.65	122.5	102.5
2	AREA 2	122	48.81	65.12	61.95	49.88	60.3	77.85	52.53	63.7	51.29	61.46	58.49	82.52	46.56	78.14	39.47	46	52.2	43.79	61.23	67.25	54.47	62.11	72.79	64.26
3	AREA 3	135	64.88	49.98	69.67	91.25	64.4	96.99	75.2	63.96	46.38	59.87	87.2	86.84	87.95	44.91	96.73	50.38	51.67	75.74	58.38	72.49	66.14	70.15	75.96	38.77
4	AREA 4	140	77.26	69.72	81.23	56.12	65.8	56.4	83.32	62.97	94.8	56.25	54.3	49.69	78.22	51.94	53.5	63.57	87.67	55.99	59.37	54.8	80.63	57.53	67.38	50.23
5	AREA 5	200	110.4	116.1	87.08	119.7	78.25	102.5	101.8	98.1	100	123.5	78.97	117.5	89.34	113.5	111.3	132.8	87.89	97.66	80.48	113.8	116.2	101.9	96.92	114.3
	Total energy consumption at time 't'		398.7	398.6	356	413.3	378	424.8	376.9	357.1	411.9	428.5	372.3	440.6	405.1	374.4	417.1	350.9	407.1	395.4	339.3	386.2	411.1	372.4	435.6	370.1

TABLE 2: Table containing the load profile's of all the users in area 1

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Sl.No	BUILDINGS	Sanctioned Load (kW)	Time t (hr)																						
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	House 1	6	0.89	0.83	1	0.84	0.9	0.59	1.7	3.3	5.8	5.8	1	1.8	0.74	0.7	0.8	0.5	0.52	2.49	2	2.3	2	2.3	0.7	0.88
2	House 2	20	2.848	2.66	3.2	2.69	2.88	1.89	5.3	10	18	19	3	5.8	2.37	2.3	2.6	1.7	1.66	7.97	6.4	7.36	6.4	7.36	2.24	2.82
3	Hotel 1	30	10	10.2	8	7.5	10	8.4	8.4	10	11	11	11	12	13	15	15	16	8.3	9	9	15	16.2	18.2	18.3	13
4	House 3	10	1.068	1	1.2	1.01	1.08	0.71	2	3.9	6.9	6.9	1.1	2.2	0.89	0.9	1	0.6	0.62	2.99	2.4	2.76	2.4	2.76	0.84	1.06
5	Hospital 1	20	11.4	9.39	0.24	6.74	3.24	15.9	6.2	11	3.3	12	5.3	13	13.8	15	9	1.7	4.58	18.3	3.05	16.5	10.8	19.9	1.56	8.85
6	Mall 2	30	0.4	0.45	0.4	0.4	0.3	0.3	0	0	1	20	19	21	21	21	18	17	17	26	27	27	27.5	15	13	6
7	House 4	10	1.36	1.26	1.52	1.28	1.37	0.90	2.54	5.00	8.76	8.82	1.45	2.77	1.13	1.10	1.22	0.81	0.79	3.79	3.05	3.50	3.05	3.50	1.07	1.34
8	School 1	30	3	3	3	3	3	1	2	5	10	11	15	20	20	22	20	25	20	7	4	4	3	3	3	3
9	Shop 3	14	0.18	0.20	0.18	0.18	0.14	0.14	0.00	0.00	0.45	9.09	8.64	9.55	9.55	9.55	8.18	7.73	7.73	11.82	12.27	12.27	12.50	6.82	5.91	2.73
10	Hospital 2	30	17.1	14.1	0.36	10.1	4.86	23.9	9.3	16	5	18	7.9	20	20.7	23	14	2.5	6.87	27.5	4.575	24.8	16.2	29.9	2.34	13.3
		200	48	43	19	34	28	54	38	64	71	121	73	107	103	110	89	74	68	117	74	115	100	109	49	53

A solved example with general equations is explained below.
'n' is the number of areas in a given region.
't' denote the hourly time variable in a day, i.e., between 0-24 hours.
The power supply available to area 'n' at time 't' be P_n^t.

Let the sanctioned load of each area is S_n

Assume the cost of energy from the grid set by the electricity board is G_n= 5
The total cost of power consumption to be paid by the user for a day (or 24 hours) be 'C'

This algorithm has 2 steps before we have a fare distribution of power.

Considering table 1 area 1 at an hour 9,

t=9,

P_1^9=119.4
total power supply required at time 't' by all the areas put together or by a substation is A^t

From the table 1

A^9 = 411.9Kw

Considering a shortage of power supply by 20% i.e. around 82.38 Kw, the net supply available during shortage is a^t

a^9= (411.9-82.38) = 329.52Kw

This new availibility of power supply is further divided or redistributed based on the sanctioned power S_n instead of cutting an individual area's power supply completely the algorithm uses brood force method to tabulate the new power supply available to each area this is represented as p_n^t.

p_n^t =(a^t/A^t)*P_n^t.

p_1^9= (329.52/411.9)* 119.4= 95.52

Each area is assumed to have 10 establishments as shown in table 2, now the new supply availability of each area has to be further fairly distributed amongst these 10 establishments, for this that same above mentioned algorithm is further broken down and the new supply availability is generated for each establishments.

The MATLAB methodology to model the demand side management optimization and scheduling are described

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in this section. The MATLAB code is structured in such a manner that it fetches all the input data from various excel files, these excel files can be edited for demand, for the individual load power characteristics, for the load start time, the load run time, for forecasted outage start time & outage duration etc., Once these inputs are ready we can go to the MATLAB GUI to run the code. Once the code is run for a forecasted outage it results in a new load schedule for the following day depending on the outage. Due to the unreliable grid, we have assumed an error in the outage scenario of maximum of 1 hour on either sides of the forecasted outage. Thus to simulate this unreliable grid we do a real time fuzzy logic based DSM on the loads by creating an error in the outage either in the outage start time or outage end time or even both. Thus depending on the actual outage the fuzzy logic rule base is referred for a further correction in the load schedule to reach to the best optimal cost. The baseline costs assumed for the grid is 5c/KWhr (residential) and the baseline diesel costs assumed in the simulation are 20c/KWhr. As the power characteristics of the loads are not constant we have divided the day into multiple of a 5 minutes chunk, so 24 hours is considered as288 chunks, by doing this we can be very accurate in calculating the effective cost, for a better and simple understanding we have assumed all the heavy loads considered in the paper i.e. 3 Geysers, 1 washing machine,1 dishwasher & a dryer to have flat power characteristics curves.

III. GAME FORMULATION & METHODOLOGY

Now after the partial outage the balance required load is supplied by the diesel generator, hence from now this paper explains how a non-co-operative game theory based demand side management between 2 players during an outage, the player A is the diesel generator & the player B is the residential consumer has been for- mulated for a much effective diesel backup cost optimization.

Typically as shown in the **Figure 1** the home load curves have 2 peaks one in the morning & the other in the late afternoon [7,8].

Hence as shown in **Figure 2** we can categories the Indian home loads into 2 segments the passive loads & the other is the interruptible loads.

The below **Table 1** shows that at each hour how are the loads distributed & what is the power consumption of each device. Assumptions are as follows grid cost per unit of energy is 5Rs & back-up cost per unit of energy is 20Rs.

During a power-cut the loads are supplied by the diesel generator which is 4 time the grid cost, now in the existing system there is no kind of demand side management prevailing to reduce the back-up cost [9-15].
A unique game theory based demand side management has been developed to reduce the back-up cost & also to have a control on the individual loads & their constraints. Below is a small worked example of this model [16].

General Terminologies

Let ' N ' denote the set of users Let 'H ' denote set of hours in a day ' h ' denote each hour h ∈H Let 'lnh ' denote total load of user n at hour h Lh total load at hour h

Figure 1. Typical emerging market home load curve.

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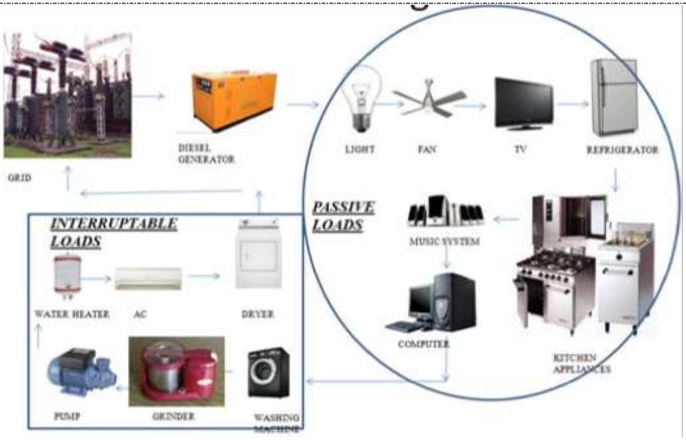

Figure 2. Typical Indian home loads.

Table 1. Load curve distribution with the wattages.

24 hour	12 hour		loads		
				Grid Cost	0.05
1	12am	750	A/C (400) + Fridge (200) + Fan (150)	Back-up cost	0.2
2	1	600	A/C (400) + Fridge (200)		Day (1-24)
3	2	600	A/C (400) + Fridge (200)	blackout start time	5
4	3	600	A/C (400) + Fridge (200)	blackout end time	9
5	4	600	A/C (400) + Fridge (200)		
6	5	600	A/C (400) + Fridge (200)	total blackout hours	4
7	6	3480	Geyser1 (1000) + Geyser II (1000) +Geyser3 (800) +Fridge (200) + A/C(400) + 2 TB lights (80) + Fan(130) [illegible]		
8	7	3090	Geyser1 (1000) + Geyser II (1000) +Geyser3 (800) +Fridge (200) + 2 TB lights (80) + Fan(130) [illegible]		
9	8	400	2 TB light (80) + Kitchen loads (120) + Fridge (200)		
10	9	400	2 TB light (80) + Kitchen loads (120) + Fridge (200)		
11	10	290	Fridge (200) + 3 CFL (90)		
12	11	300	Fridge (200) + Tv (100)		
13	12pm	800	Fridge (200) + Tv (100) + Kitchen (100) + A/C (400)		
14	1	2400	Dishwasher (800) + Dryer (700) + Fridge (200) + Tv (100) + Kitchen (200) + A/C (400)		
15	2	2400	Dishwasher (800) + Dryer (700) + Fridge (200) + Tv (100) + Kitchen (100) + + A/C (400)		
16	3	2400	Washing Machine (1500) + Fridge (200) + Tv (100) + A/C (400) + Computer (200)		
17	4	700	A/C (400) + Fridge (200) + Tv (100)		
18	5	390	Fridge (200) + Tv (100) + 3 CFL (90)		
19	6	820	Fridge (200) + 4 TB lights (160) + 2 bulbs (80) + 3 CFL (90) + 2 Fan (300) + Fancy lights [illegible]		
20	7	620	Fridge (200) + 4 TB lights (160) + 2 bulbs (80) + 3 CFL (90) + 2 Fan (300) + Fancy lights [illegible]		
21	8	830	Fridge (200) + 3 TB lights (120) + 1 bulbs (40) + 3 CFL (90) + 1 Fan (150) + Tv (100) +Kitchen [illegible]		
22	9	820	Fridge (200) + 3 TB lights (120) + 1 bulbs (40) + 3 CFL (90) + 1 Fan (150) + Tv (100) +Kitchen [illegible]		
23	10	1220	Fridge (200) + 3 TB lights (120) + 1 bulbs (40) + 3 CFL (90)+ Computer (170) + Music System (100) + Tv (100) + A/C (400)		
24	11	1100	A/C (400) + Fridge (200) + Tv (100) + 4 TB lights (120)+ 2 Bulbs (80) + Computer (200)		
25	12am	790	A/C (400) + Fridge (200) + 3 CFL (90) + Tv(100)		

L_{peak} *maxtotal load* L_{avg} *average total load*

$U_{g,h}$ *unit grid cost for that hour* $U_{b,h}$ *unit black-up cost for that hour* $t_{b,s}$ *blackout start time* $t_{b,e}$ *blackout end time* $C_{g,h}$ *cost of electricity for that hour supplid by the grid* C_h *denotes the cost of electricity for that hour (paid by the consumer)* $C_{b,h}$ *cost of electricity for that hour supplied by backup*

A_n *set of house hold appliances of user n a* $\in A_n$

' a' each appliance a $\in A_n$

$H_{n,a}$ *is a set of operating hours of appliance ah*

$x^{n,a}$ *energy consumption of appliance a at hour h by user n* $\in$

$\alpha^{n,a}$ *earliest start time of appliance a of user n l*

$\alpha^{n,a}$ *latest start time of appliance a of user n e*

$\beta^{n,a}$ *earliest end time of appliance a of user n l*

$\beta^{n,a}$ *latest end time of appliance a of user n* $E_{n,a}$ *total energy consumption of appliance a of user n*

Input values to be given by the user

$hC_h, C_{g,h}, C_{b,h}, U_{g,h}, U_{b,h}, t_{bs}, t_{be}, x^{n,a}$

The above set of values must be given by the user before running the algorithm.

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General equations

$h \in H = \{1 \ldots 24\}$ $L_h = \sum l_n^h$

$n \in N$ $L_{peak} = \max_{n \in N}(L_h)$

$L_{avg} = (\frac{1}{H}) \sum L_h$ $n \in N$

$\bar{h}$

$\sum$

$l_n^h = x^{n,a}$

n $a \in A$

el_h $\beta^{n,a}$ or $\beta^{n,a}$ $\sum$ $x^{n,a} = E$

el n,a $h = \propto^{n,a}$ or $\alpha^{n,a}$

$C = CC + h$ g,h b,h

General constraints

$elel_{\propto}^{n,a} < \alpha^{n,a} < \beta^{n,a} < \beta^{n,a}$

h $x^{n,a} = 0$ $\forall h \in H \setminus H_{n,a}$

Optimization equation

$C = CC + h$ g,h b,h

In this non-co-operative game theory the home consumer is the player 'A' and diesel generator acts as player 'B' see **Figure 3**.

When there is normal grid supply for an hour $C_{b,h} = 0$ & when there is a blackout for an hour $C_{g,h} = 0$ thus when there is a blackout for a certain portion of an hour then

$C = CC + h$ g,h b,h

$C_{b,h} = 4\ C*_{g,h}$, for simplicity we have assumed that the player B has 4 moves to play. B-player 'B'(DIESEL GENERATOR) A-player 'A'(USER) K-be the number of strategies of player 'B'

'kz'-strategies of player 'B' M-be the number of strategies of player 'A' 'mi'-strategies of player 'A' 'Pj'-payoff of player 'A' 'z'-set of positive integers { 1, 2, 3,.....,M} ***Governing equations***

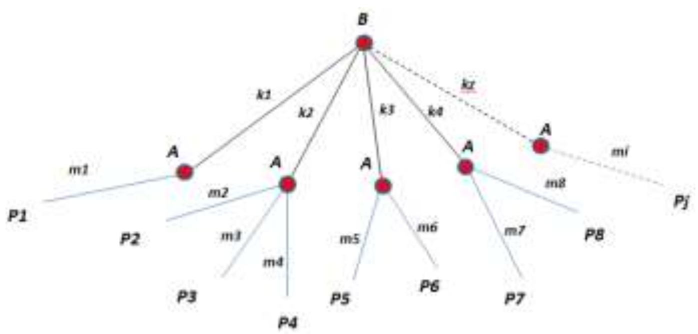

Figure 3. Tree model of the non-co-operative game theory

k=$(C\ l^{h} *Z)*/U\ \ Z\ g,hn\ b,h$

Where $Z \rightarrow \{1,2,3,.....M\}\ k = (C\ l^{h} *1)*/U$

$1\ g,h\ n\ b,h\ k = (C\ l^{h} *2)*/U$
$2\ g,h\ n\ b,h\ ...$

$k = (C *l^{h} *M)/U\ Mg,hn\ b,h$

$\sum^{h} l^{h} = x^{n,a}$
$n\ \ a \in A$
$hhhh\ h\ \ l^{n} = x^{n,1} + x^{n,2} + x^{n,3} + \square + x^{n,a}$

For example strategies of player A are
$hm1 = x^{n,1}$

Now consider during the power-cut region shown above in **Figure 4**, the loads that are operative in that hour are the ones shown above in **Figure 5** with reference to **Table 1**.

With reference to **Figure 4** blackout happens from h = 6 to h = 7 from the load profile we learn that the load during that hour of power-cut is 3 Kw [17-19].

$6666\ \ 3kw = x^{1,\ geyser\ A} + x^{1,\ geyser\ B} + x^{1,\ geyser\ C} + x^{1,\ passive\ loads}$

Strategies of player 'A', this means that the player 'A' has the option to turn on the combination of these loads as shown below.
$hh\ n,1\ n,2$
$m2 = x\ x +\ \ hhh\ h$
$mi = x^{n,1} + x^{n,2} + x^{n,3} + \square + x^{n,a}$
Strategies of player 'A' 6
$m1 = x^{1,\ passive\ loads}\ 0.6kw =$
$66\ \ 1, geyser\ A\ 1, passive\ loads$
$m2 = x + x = 1.4kw$ 66
$m3 = x^{1,geyserA} + x^{1,geyserB} = 1.6kw$

Figure 4. Load curve with blackout shown in the morning region

Figure 5. Loads that fall under the blackout region

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$m4 = x^{1, geyser\ A} + x^{1, geyser\ B} + x^{1, passive\ loads} = 2.2kw$

666 $m5 = x^{1,geyser\ A} + x^{1,geyser\ B} + x^{1,geyser\ C} = 2.4kw$

6666 $m6 = x^{1, geyser\ A} + x^{1, geyser\ B} + x^{1, geyser\ C} + x^{1, passive\ loads} = 3kw$

Similarly player 'B' also has an option to supply power at various prices, the strategies of player 'B' will an integral multiple of the actual grid cost for that hour

Let Grid cost = Rs 5/kwh Back-up cost = Rs 20/kwh

$C_{g,h}$ $=Rs15/hour$ $U_{b,h}$ $=Rs20/unit$ Strategies of player 'B' $K1=0.75kw$ $K2=1.5kw$ $K3=2.25kw$ $K4=3kw$ For K1 the possible moves by player 'A' is m1 For K2 the possible moves by player 'A' is m2 For K3 the possible moves by player 'A' is m3 & m4 For K4 the possible moves by player 'A' is m5 & m6 Thus for each move of player 'A' there is a unique payoff.

IV. RESULTS

In this section, key results and benefits from the MATLAB Tool for the game theory load-scheduling of residential loads for diesel mitigation are discussed.

The savings results in this algorithm depends highly upon how the consumer chooses his strategy & what are his requirements during that hour, the savings may result from as high as 75% to 45%.

V. CONCLUSION

Use of simple real time non-co-operative game theory techniques to mitigate the diesel consumption during power outages in developing countries shows significant cost savings potential by massive reduction in diesel consumption by choosing the correct strategy. The study also showed that the actual savings potential depends on the timing of power outage, duration and the specific load characteristics. As diesel prices increase, the economic benefits of load-shifting are also increase correspondingly.

DSM policies for developing countries should consider specific approaches to mitigate power outages and provide relief to customers. Clearly, challenges exist in implementation of DSM policies since most consumers in India and frugal markets have outdated appliances that are unintelligent with a severe need to develop low-cost smart network-controllable solutions as a retrofit.

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