Study of Performance of a Power Station for Operational Optimization

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ABSTRACT

Undertaking regular performance analysis of a power station is very much necessary for its operational optimization. In this regard as a case study a 630 MVA, 400/220 kV power station was identified and analysed to study its performance. The study shows that the installed station (transformer) capacity is very large compared to the load it had to supply, and also it is under loaded and underutilized for the major period of its operation. Due to this the operational efficiency of the station was reduced and also the incoming voltage level was higher than the voltage for which the station was designed. During off peak loading condition, one of the 400 kV incoming lines was being tripped, thus risking the supply reliability. This case study emphasizes and suggests few ways for improving the performance and loading pattern of the power station by optimization of its operational parameters.

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1. INTRODUCTION

Electrical power is vital for the increase in productivity, development, prosperity and strength of any nation. Thus its requirement has increased manifolds. However, the power generation capacity has not been able to cope up with the demand, which is mainly due to slow rate of increase in power generation, energy pilferages, transmission and distribution (T&D) losses, scarcity of the conventional sources of energy, poor utilization of non conventional (renewable) energy sources, rise in the population and their living standards, wastage of power due to the lack of awareness for energy conservation etc. This combined with the degradation of power quality has further widened the power shortage which needs to be bridged and controlled urgently.

The power shortage could be tackled by adopting following techniques [1], [2]:-

a. Increasing the power generation capacities.
b. Maintaining a qualitative power supply.
c. Adopting techniques for energy conservation and improved efficiency.

Attempts to increase generation capacities through utilization of more and more fossil fuels have proved counterproductive and have lead to environmental problems. However, continuous research and studies on the use of the non conventional sources of energy with better and efficient technology would help in controlling pollution as well as improving the power generation capacity.

Quality power supply is ensured with good initial plant design, effective correction of equipments, co-operation between the suppliers and consumers, and frequent monitoring and maintenance. Amongst the techniques suggested, the last one is simpler, effective, environmental friendly and most economical.

However, it needs judicious use and planning of the operations by adopting an effective scientific methodology and a tool, like Energy Audit [3]. Immediate benefits of this would be:
1) Reduced energy bills and imports of fuels
2) Emission control and environment conservation
3) Increased productivity, competitiveness, quality and profits for industries and businesses
4) Improved energy security and its sustainable development

In this regard a study of performance and operational optimization was carried out for a 400/220 kV substation installed in one of the state in India.

The brief technical details of the sub-station are as follows:

- No. of transmission lines: a) 400 kV – 2 nos., (b) 220 kV - 4 nos.
- Power transformers: 2 nos, 315 MVA each, No load voltage ratio HV/IV/LV-400/220/33 kV, No load loss - 101.4 kW, Load loss -274.1 kW,
- Bus-reactor (shunt):1 no, Rated power - 50MVAR, Phases-3, Frequency–50 Hz, , Rated voltage – 420 kV.

This 400/220 kV substation is fed through two 400 kV lines. The power carrying capacity of each line is about 650 MVA. Thus in case of emergency and requirement even one line can take care of the loading of the two installed transformers each of capacity 315 MVA. Both the incoming lines are connected to two 400 kV buses which are normally coupled through a bus coupler. Also provision is already made for bringing an extra (third) line whenever need arises, this would increase the total station power input capacity to 1950 MVA. Also there is a provision for installation of a third transformer of 315 MVA, so as to increase the station output capacity to 945 MVA. Presently there are four 220 kV outgoing lines and there is provision for installation of more 220 kV lines as per the load requirement.

2. PERFORMANCE ANALYSIS

The substation operational data logged in an automatic data logger as well as recorded manually on hourly and four hourly intervals and spanning over a period of 18 months was collected and studied for the analysis purpose. The sample data logging is as shown in Table 1 and 2. The calculated performance parameters are presented in Table 3. The sample calculations of the parameters are as shown below:-

1) Power factor = Output MW/Output MVA = 171/177.07 = 0.9657 (lag)
2) % station loading= (Station Output MVA/630 MVA) x 100= (177.07/630) x 100 = 28.1063 %
3) Transformer Load loss = $(\% \text{ loading } /100)^2$ x F.L loss = $(28.10/100)^2$ x 274.1 = 21.643 kW
4) % station efficiency (considering power in MVA)= (Station output MVA/Station input MVA) x100
= (177.07/207.88) x 100 = 85.17 %.
5) % efficiency of each transformer (considering losses)= (Output KW/ output KW+ losses) x100
= ($315\text{x}10^3$ x PF x % loading/100) / [($315\text{x}10^3$ x PF x % loading/100) + copper loss + No load loss]
= [($315\text{x}10^3$ x 0.965 x 28.1063/100) / ($315\text{x}10^3$ x 0.965 x 28.1063/100) + 21.643+ 101.4] x 100= 99.85 %
6) % loading at which transformer efficiency is maximum.i.e. Copper loss = No load loss
$(\% \text{ loading } /100)^2$x274.1 = 101.4 kW
(% loading/100) = √ (101.4/274.1) = 60.82 %

The station performance analysis data (given in Table 3) is represented graphically in Figure 1. It shows that there is a large difference in the values of station efficiency and actual transformer efficiency, which in the ideal condition should have been nearly the same. For calculating station efficiency station input and output (in MVA) was considered. However, for calculating the transformer efficiency the actual transformer loading (in MW), no load and full load losses have been considered.

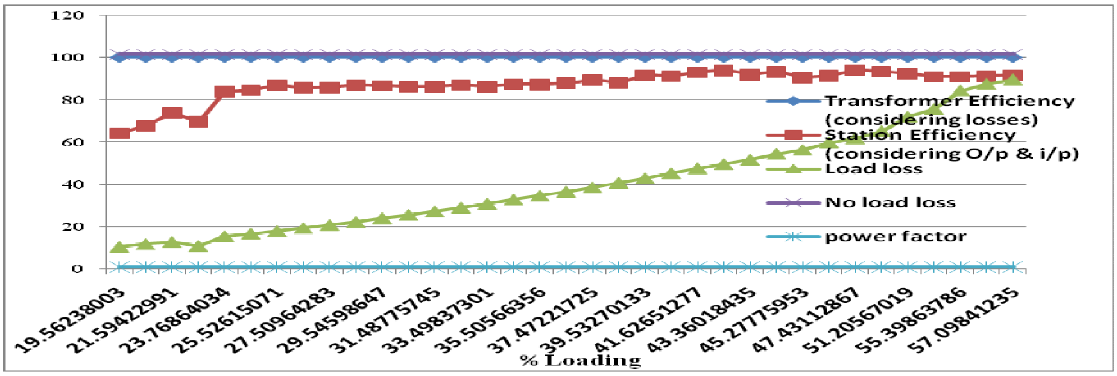

Figure 1. Graph of variations in substation performance parameters

3. RESULTS AND ANALYSIS

Based on the present operational pattern followed at this station, the collected field data and results obtained from the performance analysis, the following observations have been made:-

1 The station input voltage varies widely between 435 kV to 390 kV. But when 50 MVAR bus shunt reactor is in ON condition, the voltage variation comes down to between 420 kV to 390 kV. The shoot up in the voltage is mainly due to the light loading of the lines and the Ferranti effect, which is dangerous to the life and operation of the transformer and other station equipments.
2 The station output voltage varies between 232 kV to 220 kV.
3 Frequency variation is between 49 to 50.5 Hz.
4 In addition to 50 MVAR shunt bus reactor installed at this substation, one more line reactor of capacity 80 MVAR is installed at the sending station end for controlling the voltage levels. However, in spite of this additional reactor the voltage level during light loading periods reaches up to 420 kV which is still on the higher side compared to the rated incoming voltage level of 400kV. Hence, almost every day during light loads (particularly in the night hours), one of the 400 kV incoming lines is forced to be tripped, as a last resort to control the incoming voltage rise.
5 Both the transformers are kept in ON condition continuously and are being operated in parallel. Hence they share the load equally.
6 Loading of each transformer normally varies in between 19 to 60 %.
7 The maximum loading of each transformer does not cross 60 % even during the peak periods of loading, (which are generally of small duration). Hence, during major period of any given day both the transformers are under loaded.
8 Each transformer operates at a power factor of 0.9 lag and above.
9 The outgoing voltage on the transformer secondary side (220 kV side) is normally not regulated using the OLTC and the tap position is kept fixed at number 10. Thus the high incoming voltage is passed on as it is to the various distribution substations in the state that are fed by this substation.
10 The average of the transformer efficiency calculated from its output and losses is above 99.5 % and does not vary with the transformer loading. But the overall station efficiency considering the station power output and input in MVA varies directly with the transformer loading and is in the range of 60 % to 93 %. Ideally the transformer efficiency and the station efficiency calculated by methods as explained above should have been matching. However the same differ.
11 The tertiary winding of the 315 MVA transformer, which has been converted into 800 KVA tertiary transformer, is used to feed the station auxiliary loads only in cases of emergency. Because the station auxiliary load normally draws the supply from separate transformer of 630 KVA capacity fed by Government owned utility and this auxiliary load is very small compared to the main transformer loadings. Hence, the power consumption by the tertiary transformer, if any, is negligible and is not taken into account for the calculation purposes.
12 Presently there is no metering in place for recording transformer power factor, tertiary transformer performance and bus reactor performance. The presence of these metering would have certainly enhanced the analysis.

4. CONCLUSIONS AND RECCOMENDATIONS

Based on the observations and detailed analysis of the station performance, the following conclusions are drawn and accordingly suitable recommendations have been made for energy conservation as well as for optimization and improvement in the station operational efficiency:-

1. The condition derived for these transformers to attain its maximum efficiency is to operate each of them at 60.82 % loading. Presently these transformers are loaded between 19 to 60 %. The loading is near to 60 % for very small duration and it is generally well below this value for the major duration on any given day. It is a usual practice to design transformers to give higher efficiencies at higher percentage loading. Hence following modifications in the station/transformer operations may be adopted [4], [5] :-
   i) When station loading is in the range of 30 to 45 %, only one transformer should be operated, since under this condition it would get loaded to between 60 to 90 % where it would yield maximum efficiency.
   ii) When station loading is below 30 %, only one transformer should be operated. This operation would improve the efficiency of the operating transformer and additionally save the iron losses that would have occurred in the second transformer.
   iii) When station loading is above 45 % (i.e. one transformer would get loaded above 90 %), the second transformer must be brought into operation in parallel with the first transformer. This is to prevent the overloading of the single transformer.

2. With the implementation of the above measures (as given at serial no. 1), there may be chances of decrease in the Insulation Resistance (IR) value of the transformer which is kept in OFF condition. This is mainly due to the high humidity and heavy rainfall in this area. This limitation can be overcome by switching OFF one of the two transformers in a phased manner and alternatively.
3. An alternative to the above suggestion (as suggested at serial no. 2) would be to open the outgoing 220 kV side circuit breaker of one transformer while keeping its primary side connected to the 400 kV supply (instead of switching it OFF). By doing this, only the load on this transformer could be transferred on to the second transformer, which is also in operation. The no load losses of 101.4 kW suffered due to adoption of this measure could very well be compensated by the power that would be saved even if the efficiency of the loaded transformer improves by a small percentage.
4. Due to the adoption of the suggestion (as mentioned at serial no. 3 above) the changeover time required for shifting the load from the loaded transformer on to the idle transformer, in case of emergency due to the tripping of the loaded transformer, would be extremely small, thus not affecting the system reliability to a larger extent.
5. The loading ability of the incoming lines normally expressed in terms of Surge Impedance Loading (SIL), can be used as a convenient "yardstick" for measuring relative loading ability of lines operating at different nominal voltages. Also a line loaded to its SIL is characterized by a uniform voltage profile along its length and reactive self-sufficiency. Hence, the loading of these 400 kV lines may be reassessed and planned according to the SIL [6].
6. For the purpose of controlling rise in the incoming voltage on account of the lightly loaded supply lines (which is due to less power drawn by the State through this substation), switching ON of bus and line reactors along with tripping of one 400 kV incoming line is adoptedat present. However, this makes the station operation tedious and causes an additional loss of power in the reactors, thus affecting the system efficiency, economics and reliability. To overcome this drawback, it is suggested to request the State for drawing its total power requirements (which is about 450 to 500 MW during peak hours) through this substation, so that it is loaded near to its full capacity.
7. It is difficult to ascertain the reasons of mismatch between the transformer and station efficiency due to no metering in place for recording performance of the bus reactor. Hence it is assumed that the station efficiency is getting hampered due to loss of power in some of the station equipments other than the 315 MVA transformers and more so in the 50 MVAR shunt bus rector (which is the only equipment where such large amount of power may be absorbed). Thus the use of the bus reactor should be curtailed as much as possible by adopting means as suggested hereinabove.
8. The power loss and the corresponding reduction of station efficiency due to continuous switching ON of a conventional shunt reactor (as mentioned at serial no. 7 above), may be minimized by replacing it with a suitably designed Thyristor Controlled Reactor (TCR). The TCR may be connected in conjunction with harmonic filters through a Static VAR Compensating (SVC) step down transformer as shown in the Figure 2 below[7], [8].

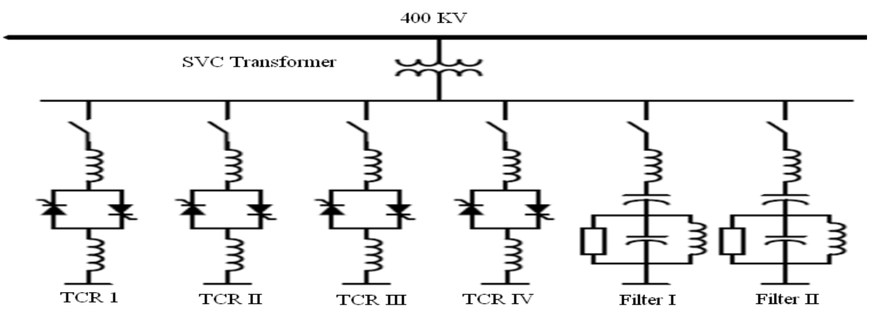

Figure 2. Connection of TCRs, SVC and Filters

9. It is learnt that the overcapacity of this station in the present scenario is due to the reason that at the time of assessing the projected station capacity in the year 1998, the power requirement of the State was projected to grow to 750 MW + 20 % by the end of 11^{th} Five Year Plan. Unfortunately the projection of station capacity could not be realized till date for various reasons. This has forced the station to operate well below 60 % of its capacity for most of the period. Hence, it is suggested to once again immediately study and reassess the future power requirement of the State and to decide as well as plan foresightedly the operational strategy for this station.

10. One more option for optimizing this station capacity would be to trim and tailor its capacity as per the present power requirements of the State [9]. Hence, the existing two numbers of 315 MVA transformers may be replaced by two 250 MVA transformers, so that 500 MVA capacity can take care of the present total power requirement of the State which is maximum 450 MW during peak hours. During off peak hours, only one transformer can take care of the total State power requirement. The cost of the new transformers may be recovered from the sale of 315 MVA transformers and by the subsequent energy savings by 250 MVA transformers. This would considerably reduce the payback period. Else these 315 MVA transformers may be used by this power company at their other/new substations whenever required.
11. Also the State may be requested to increase its electrical power allocation from the central government and promote industrialization in the state by release permissions to the projects that are held up due to power shortage problems in the state. This would serve the purpose of the state and also help in utilization of full station capacity [10], [11]. This may increase the load on this station and absorb the reactive power from the incoming lines, hence curtailing the use of 50 MVAR bus reactor.
12. Presently this station is supplying power to only one State. An alternative suggestion to increase the optimum utilization of the station capacity could be to consider the feasibility of diverting its remaining and additional capacity to fulfill power requirements of the neighboring states and consumers.
13. It is further suggested that the metering for recording transformer power factor, tertiary transformer performance and bus reactor performance may be put in place immediately for improved data recording and analysis purpose.

The recommendations proposed in this paper are very much feasible, attractive and are technically as well as commercially viable for their adoption keeping in view the wider perspective of energy conservation.

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Table 1. Sample data sheet of the substation operations (at hourly intervals)

TIME	400KV LINE I (I/P)		400KV LINE II (I/P)		400 KV BUS		220 KV BUS		220KV LINE I (O/P)		220KV LINE II (O/P)		220KV LINE III (O/P)		220KV LINE IV (O/P)		TOTAL STATION INPUT			TOTAL STATION OUTPUT		
HRS	**MW**	**MVAR**	**MW**	**MVAR**	**KV**	**HZ**	**KV**	**HZ**	**MW**	**MVAR**	**MW**	**MVAR**	**MW**	**MVAR**	**MW**	**MVAR**	**MW**	**MVAR**	**MVA**	**MW**	**MVAR**	**MVA**
1	180	-104	0	0	410	49.70	224	49.75	48	19	47	18	38	3	38	6	180	-104	207.88	171	46	177.07
2	178	-104	0	0	410	49.84	223	49.85	48	19	47	18	38	3	38	4	178	-104	206.15	171	44	176.57
3	178	-102	0	0	411	49.93	225	49.94	51	21	50	19	35	0	35	3	178	-102	205.15	171	43	176.32
4	160	-94	0	0	413	49.60	226	49.62	44	19	43	18	33	-1	32	1	160	-94	185.56	152	37	156.43
5	170	-97	0	0	412	49.60	224	49.60	46	19	45	18	35	0	35	2	170	-97	195.72	161	39	165.65
6	173	-99	0	0	409	49.62	225	49.62	48	20	47	18	37	0	38	2	173	-99	199.32	170	40	174.64
7	183	-99	0	0	410	49.82	225	49.85	50	19	49	18	39	1	41	3	183	-99	208.06	179	41	183.63
8	176	-99	0	0	409	49.90	222	49.90	48	20	47	19	38	0	38	1	176	-99	201.93	171	40	175.61
9	185	-107	0	0	400	49.84	220	49.84	50	22	49	21	41	3	41	5	185	-107	213.71	181	51	188.04
10	200	-127	0	0	396	49.56	218	49.55	57	31	57	29	41	6	41	7	200	-127	236.91	196	73	209.15
11	205	-133	0	0	390	49.46	222	49.46	59	32	59	30	43	6	43	8	205	-133	244.36	204	76	217.69
12	107	-75	105	-73	416	49.64	227	49.65	61	35	59	33	42	9	42	10	212	-148	258.54	204	87	221.77
13	109	-72	107	-70	415	49.70	228	49.70	59	31	59	29	44	8	45	10	216	-142	258.49	207	78	221.20
14	105	-68	105	-68	409	49.39	225	49.40	59	32	59	32	42	6	40	7	210	-136	250.19	200	77	214.31
15	112	-73	112	-73	411	49.73	224	49.73	58	32	58	32	49	12	50	12	224	-146	267.37	215	88	232.31
16	109	-70	109	-70	412	49.90	225	49.90	57	31	57	31	47	9	47	11	218	-140	259.08	208	82	223.57
17	105	-68	105	-68	410	49.72	226	49.70	58	31	58	31	43	9	43	9	210	-136	250.19	202	80	217.26
18	100	-70	100	-70	414	49.88	227	49.88	58	31	58	31	40	7	40	9	200	-140	244.13	196	78	210.95
19	100	-68	100	-68	415	49.69	227	49.68	56	30	56	30	40	8	40	9	200	-136	241.85	192	77	206.86
20	104	-70	104	-70	418	49.53	227	49.53	62	29	62	29	30	10	37	12	208	-140	250.72	191	80	207.07
21	94	-65	92	-63	419	49.40	228	49.42	58	24	57	23	31	9	31	10	186	-128	225.78	177	66	188.90
22	94	-58	92	-58	418	49.67	228	49.67	56	22	56	21	33	6	33	7	186	-116	219.20	178	56	186.60
23	97	-53	95	-53	420	49.66	229	49.68	55	19	54	18	38	4	38	6	192	-106	219.31	185	47	190.87
24	0	0	175	-97	411	50.11	230	50.11	52	21	52	20	34	-3	34	0	175	-97	200.08	172	38	176.14

Table 2. Sample data sheet of Transformers & Bus Reactor (at 4 hourly intervals)

TIME	TRANSFORMER I						TRANSFORMER II						
	HV CURRENT			HV POWER		TAP POS.	HV CURRENT (IN AMPS)			HV POWER		TAP POS.	BUS REACTOR (MVAR)
HRS	R(A)	Y(A)	B(A)	MW	MVAR		R(A)	Y(A)	B(A)	MW	MVAR		
04:00	165	165	165	82	28	10	165	165	165	82	28	10	48
08:00	170	170	170	90	29	10	170	170	170	90	29	10	49
12:00	180	180	180	108	54	10	180	180	180	108	54	10	49
16:00	160	160	160	110	50	10	160	160	160	110	50	10	48
20:00	160	160	160	104	50	10	160	160	160	104	50	10	50
24:00	145	145	145	90	29	10	145	145	145	90	29	10	50

Table. 3. Data sheet of Performance Analysis of the Station under varying conditions (over the period of study)

P.F (LAG) (OUTPUT MW/ MVA)	% LOADING (OUTPUT MVA/630)	% STATION EFFICIENCY (OP MVA/ IP MVA)	TRANSFORMER KVA RATING	NO LOAD LOSS (KW)	LOAD LOSS (KW)	% TRANSFORMER EFFICIENCY	DIFF. OF % EFFICIENCY
0.899323	19.23846194	60.86343298	315000	101.4	10.14494583	99.9981326	39.13469961
0.958875	20.69222811	67.44055339	315000	101.4	11.73609322	99.99836959	32.5578162
0.959247	21.34610823	69.67900614	315000	101.4	12.48954019	99.99841911	30.31941297
0.96645892	23.486164	75.4509891	315000	101.4	15.11935324	99.99857017	24.54758107
0.926258	24.84824183	80.35928177	315000	101.4	16.9238967	99.99858699	19.63930522
0.91884	26.94909023	81.30113227	315000	101.4	19.90660746	99.99868148	18.69754921
0.94045331	28.01755919	81.90682024	315000	101.4	21.51640111	99.99875798	18.09193774
0.94288605	28.11361609	82.82499287	315000	101.4	21.66418997	99.99876514	17.17377227
0.97618706	29.2683951	83.12645377	315000	101.4	23.48047367	99.998851	16.87239723

0.93698	29.98487903	83.66483039	315000	101.4	24.64413832	99.99882921	16.33399882
0.9449233	30.06878819	84.37614236	315000	101.4	24.78225876	99.99884202	15.62269966
0.97735788	31.50703689	85.99357473	315000	101.4	27.20972537	99.9989268	14.00535207
0.96808527	32.30070979	86.16074935	315000	101.4	28.59783573	99.99894028	13.83819093
0.93763837	34.7038727	86.98943101	315000	101.4	33.01147417	99.99897195	13.00954094
0.93157762	34.92965252	87.36816767	315000	101.4	33.44240993	99.99897094	12.63080327
0.92412505	35.72662926	87.96127639	315000	101.4	34.98590577	99.99898207	12.03770568
0.94323534	35.84420813	87.37376716	315000	101.4	35.21656689	99.99900541	12.62523825
0.93117796	36.137876	88.02440492	315000	101.4	35.79598211	99.9989993	11.97459438
0.95326054	37.29888541	88.07039769	315000	101.4	38.13297984	99.99904729	11.9286496
0.91892786	37.82876378	88.52004431	315000	101.4	39.22413127	99.99902272	11.47897841
0.96637248	38.27108884	88.67316364	315000	101.4	40.14677576	99.99907915	11.32591551
0.95726389	38.96688001	89.94106945	315000	101.4	41.61983018	99.99908325	10.0580138
0.95334223	39.95966724	89.56037121	315000	101.4	43.76760292	99.99909677	10.43872555
0.95364172	40.61290326	89.60011777	315000	101.4	45.21027085	99.99910774	10.39898997
0.94752145	41.21027447	89.24763484	315000	101.4	46.55003905	99.99911135	10.7514765
0.94752145	42.51865152	89.64045025	315000	101.4	49.55277727	99.99913039	10.35868015
0.9367778	43.54677361	89.97083727	315000	101.4	51.97817208	99.9991342	10.02829692
0.96377223	44.63282074	89.82181908	315000	101.4	54.60315092	99.99917139	10.17735231
0.93647324	45.25591406	88.94786787	315000	101.4	56.13835954	99.99915433	11.05128646
0.94998996	48.28789534	89.66681251	315000	101.4	63.91246813	99.99919514	10.33238263
0.9671548	51.20567019	92.19278694	315000	101.4	71.86958629	99.99922921	7.806442267
0.93177739	52.46842144	90.74500391	315000	101.4	75.45795515	99.99920667	9.254202769
0.9486833	55.21437184	91.89381024	315000	101.4	83.56286218	99.99923107	8.105420827
0.94811911	56.41913836	91.07635497	315000	101.4	87.24929655	99.9992334	8.922878434
0.95033737	57.12257136	92.66566144	315000	101.4	89.43850542	99.99923636	7.333574914