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Commercial Aspects of Solar Power in Agricultural Sector – Indian Context

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ABSTRACT

The present study encompasses the requirement and feasibility of Solar Photo Voltaic Plants (SPVP) in rural India which is suffering from severe power shortage. A practical rural agricultural feeder connected at the far end of the utility system has been chosen for study. Aim of the work is to evaluate technical feasibility of SPVP in terms of voltage profile, line flows and losses before and after placement of the units. Economic analysis is carried out by evaluating the total cost of installation and income generated. The study demonstrated a considerable reduction in current from utility system and the scheme is found economically viable.

Keywords: *Distributed power generation, Photovoltaic power generation, Grid interconnection, Utility distribution system, PV inverters*

1. INTRODUCTION

1.1 Status of Indian Power Sector

India is rich in agricultural products and its economy is largely influenced by the productivity and growth in this sector. With the extension of electricity to rural areas, there has been a great spurt in the lift irrigation from tube wells and open wells. Advances in the field of ground water development have made it possible to lift ground water from depths of 60 to 100 metres and even more. India is in first place for its amount of irrigated agriculture in the world with gross irrigated area of 80 million hectares. 34 percentage of Indian cultivation depends on water either lifted from canals or bore wells [1] and hence on power. But there is a wide gap between demand and supply of electric power because of various well known reasons. Tables I&II, shows various statistics of consumption and demand in India [2].

Table I. Consumption by various sectors during 2009-2010

Industry	Domestic	Commercial	Agriculture	Others
34.93%	27.80%	8.49%	21.18%	7.60%

Power generation in India is largely dependent on coal (57.27% as on 31.03.2010 [2]) which is rapidly depleting. Generation from renewable energy (Solar, wind and others) at present is 8.68% a meager value. Due to increase in gap between supply and demand, power outages became common and the first to be effected is rural and agriculture sector. In many states in India, agriculture sector is not given required power. With non availability of electricity in rural areas, agriculture and other industries suffer, thereby reducing the prosperity and productivity. Hence it is high time to think of some alternative ways to provide reliable power for rural India. R&D is more focused nowadays in developing dispersed generation from various sources of electricity, with units of capacity ranging from 5-10KW to 10MW. The enacted Electricity Act – 2003, which allows the private utility to distribute power, provides a glimmer of hope not only for the country but more so for the rural area.

Table II: Energy shortage and T&D Losses

S.No	Year	Energy requirement MU	Energy availability MU	Energy shortage MU	Energy shortage Percentage	%Losses
1	2006-2007	690587	624495	66092	9.6	30.59
2	2007-2008	737052	664660	72392	9.8	29.24
3	2008-2009	777039	691038	86001	11.1	28.44

1.2 PV as Rural Grid Connected Systems

As discussed in previous section, specific drive for PV in India include the country's raising electricity needs, the persistent energy deficit situation, over dependence on coal, oil and gas for electricity generation coupled with more than 300 sunny days a year with radiation of 4 – 7 Kwh/m^2/day [3].

Thus there is enormous potential for on grid or off grid PV development in India, to cater to the needs of rural electrification, powering irrigation pumps, backup generation for powering cellular towers, captive power generation etc. Persistent supply demand gap, huge investments needed to build required electricity generation capacity and very high T&D losses in India's electricity grid are the factors that will make PV an attractive choice for captive power generation.

Although wind currently dominates renewable sources of power generation in the country (accounting for 70% [2] of power generated from renewable sources), solar PV is expected to outpace wind in the longer run as the renewable source of choice. India being a medium wind profile country, its low plant load factors and the saturation of optimal locations for wind generation are expected to make it less attractive than PV. Another attractive feature of PV system is that its power output matches very well with the peak demand in rural areas with agricultural feeders. Also, in contrast to the Wind firms which are to be installed in specific locations, there is no location constraint for solar power and therefore can be installed in many parts of the country.

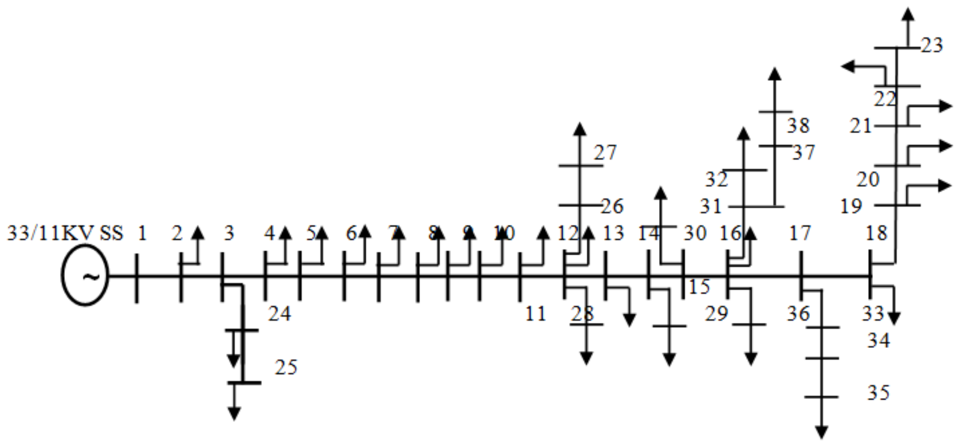

Fig I. Single line diagram of a rural feeder

As of now PV constitutes a small part of India's power generating capacity. It is being attracted with the initiatives taken by Government of India under National action plan on climate change in 2008 and Jawaharlal Nehru National Solar Mission (JNNSM) aimed at local PV production from integrated facilities at a level of 20,000MW by 2020. Most estimates suggest that well over 300,000MW of power generation capacity will to be added by 2030 to meet the country's electricity needs. Grid connected solar farms, PV installations working in conjunction with wind energy installations and the deployment of mini and smart grids present substantial opportunities. India's MNRE announced generation based incentives for grid interactive solar PV generation projects. Combined MNRE plus state utility feed in tariff of Rs. 15 per KWh [3]. Tariff guarantees cease at the end of 10 years from the start of generation. The connection of Photo Voltaic mini power to the grid in poorly served places is a well adopted solution to solve the problem of voltage drop and to provide clean energy [4]. Many authors reported the guide lines for installations of photo voltaic installations for on grid and off grid applications [5,6,7]. The impact of PV mini-power plant on voltage and load of rural LV network in Algeria is studied for one day [8]. Performance evaluation of grid connected photo voltaic systems is given in [9,10]. Present paper discusses the technical benefits and economical viability of grid connected solar power plant by utilizing the space available in agricultural farms. A practical distribution feeder is considered for the analysis. The benefits are studied with the following Solar photo voltaic plants connected to the system as specified: (a) 15KW SPVPs at each load point of a substation and (b) Certain percent of load is compensated by SPVPs.

2. DESCRIPTION OF THE TEST SYSTEM

The study was initiated with a load flow analysis conducted on the chosen rural distribution feeder in Guntur District, Andhra Pradesh. Feeder Single line diagram is given in Fig.I and the details are shown in Appendix -I. As the feeder taken for analysis is a typical rural distribution feeder, the results will therefore have a wider applicability. Sketch of the feeder is taken from the distribution substation, is often the best data available on rural distribution networks in India.

The sample feeder emerging from a 33/11KV substation, feeds power to six villages, both for domestic and

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agriculture loads through 11KV/440V 3-phase and 11KV/230V 1-Phase distribution transformers of capacities 15KVA, 16KVA, 50KVA, 63KVA and 100KVA. Distance between the substation and the farther bus is 12Km. Feeder is with 2MW peak load and base load of about 425KW. Average load factor is 0.57. The feeder load is predominantly irrigation pump sets. It supplies to 475 nos of 3-phase induction motors with either 3HP or 5HP rating. Operating PF of the motors would be on an average of 0.8 and some times as low as 0.7. The buses are numbered in sequential manner for analysis.

Out of the four main categories of the consumers on the feeder (Domestic, Commercial, Industrial, Agricultural), the agricultural loads are not metered and are not charged. The remaining three categories are charged on per KWH basis. Annual consumption on the feeder is 8.76Million Units.

3. SYSTEM STUDY

3.1 LOAD FLOW ANALYSIS

From the single line diagram developed for feeder, load flow study is conducted by vector based load flow technique [11]. Base case scenario (without PV systems) is carried out to obtain the voltage profiles and distribution losses. All conductors used in 11KV system are AAAC 34mm^2 with resistance 0.6545Ω/km and reactance 0.334Ω/km. The source current is found to be 5.42 pu and 22.89 pu during light load and full load operating conditions respectively of the network. The total real losses are found to be 7.80 KW and 140.61 KW for the two operating conditions viz., light load and full load. Output of load flow study is shown in Fig.II & Table III.

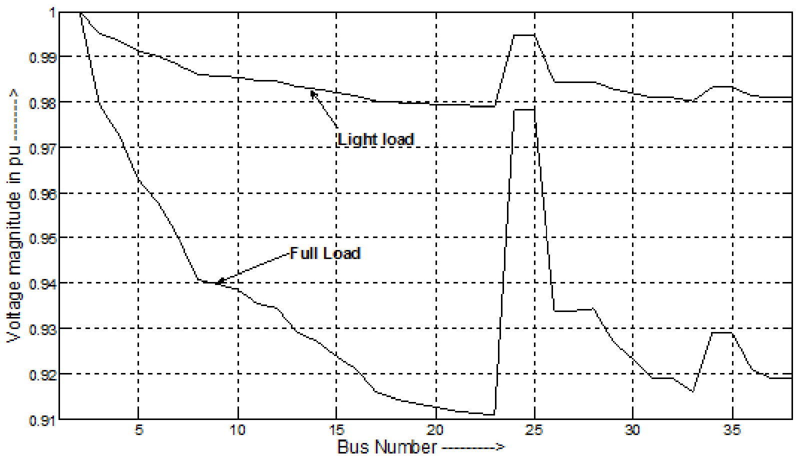

Fig II. Voltage profile of the network

Fig III. Location details of solar panels

Table III. Voltage magnitudes of various nodes without PV generation in field

Bus No.	Bus Voltage Magnitude		Bus No.	Bus Voltage Magnitude		Bus No.	Bus Voltage Magnitude	
	Full Load	Light Load		Full Load	Light Load		Full Load	Light Load
1	1	1	14	0.9828	0.9271	27	0.9844	0.9338
2	1	0.9999	15	0.9821	0.9238	28	0.9845	0.9343
3	0.9951	0.9795	16	0.9814	0.921	29	0.9828	0.9268
4	0.9936	0.9729	17	0.9802	0.9159	30	0.9819	0.9233
5	0.9912	0.9627	18	0.9799	0.9144	31	0.9809	0.9189
6	0.99	0.9577	19	0.9796	0.9135	32	0.9809	0.9189
7	0.9883	0.9503	20	0.9795	0.9126	33	0.9802	0.9158
8	0.986	0.9408	21	0.9792	0.9117	34	0.9833	0.9292
9	0.9858	0.9397	22	0.9791	0.9113	35	0.9833	0.929
10	0.9855	0.9386	23	0.979	0.9108	36	0.9814	0.9208
11	0.9848	0.9354	24	0.9949	0.9783	37	0.9809	0.9189
12	0.9845	0.9344	25	0.9949	0.9783	38	0.9809	0.9189
13	0.9833	0.9293	26	0.9844	0.9339			

3.2 Solar Power Potential in the Field

One of the schemes proposed is to place solar panels in the area available on water channels/dividers of the fields which are normally 3’ (0.914m) wide and go along the length of the fields, (Fig III).

A connection for 3HP motor will be given to a land holding of at least 2 acres (0.81 hectare). For 2 acres of agricultural land that is considered, the space left for irrigation channels/dividers is 3120sqft. 1sqft panel would produce a power of 10Wp. Hence there will be provision for placing the panels up to 31.2KW on the land available over irrigation channels of 2 acres. For a 63KVA Distribution transformer (DT), the land under cultivation is around 30 to 40 hectares, and for a 100KVA transformer the land under it varies from 40 to 70 hectares. Hence an estimate of 35KW per hectare may result in a solar potential of 1.05MW-1.4MW under 63KVA DT and 1.4MW – 2.45MW under 100KVA DT. Even a conservative estimate of 2.5KW per hectare (1KW per acre) may also yield a solar potential of 75KW – 100KW under 63KVA DT and 100KW-175KW under 100KVA Distribution transformer.

Sample Solar Panel Particulars Available

Panels dimensions: 1660mm x 990mm x 42mm

Area: 1.6 Sq Mtrs

Power output of each panel: 220W

Open Circuit Voltage Voc – 36V

Short Circuit Current Isc - 8.2A

Voltage at Maximum Power Vmp – 29.6V

Current at Maximum Power Imp - 7.4A

Parent Solar Cell Size - mm 156 Sq. Mono / Multi Crystalline

The impact of grid connected PV plant on LV grid has been performed by adopting the following model (Fig IV).

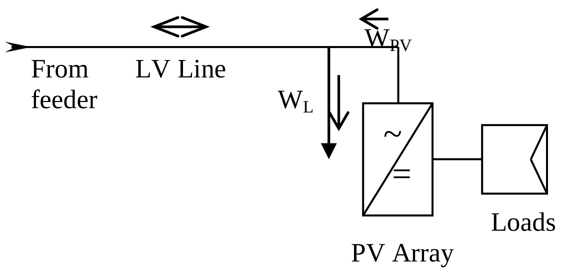

Fig IV. SPVP Model considered for the analysis

In grid connected scheme, production curves of PV plants and their power depends on the factors such as tilt and azimuth of panels, shadowing because of the nearby objects, peak power of panels and efficiency of inverter. Number of strings required and number of panels per string can be planned depending on the capacity of the plant. Analysis for the present study is done with the presumption that the solar photo voltaic system injects only real power into the system.

3.3 Economic Analysis

Economic analysis and system feasibility study is made by evaluating the annual returns and by calculating the simple payback period gives as:

$$Simple\ \ payback\ \ period\ \ =\ \frac{Total\ capital\ \ investment}{Total\ ONE\ \ year\ cash\ flows}$$

Total capital investment is taken as Rs.120 per Watt and the energy produced from 1KW solar plant per day is taken as 4.5 KWH. It is assumed that the power is purchased at Rs.15 per unit [12].

4. RESULTS AND DISCUSSION

4.1 Number of Small SPVS are Connected to LV Grid

Loads at bus number 19 are fed through 100KVA, 11KV/440V three phase transformer. Total number of irrigation motors connected on LV side of it are 23 and the connected hp load is 72hp (53.64KW). Actual LV network of this transformer is also modelled so that the effect of SPV from LV side to HV side can be determined. A solar PV generation of 15KW is assumed to be connected at each load point on the LV network of substation at bus number 19 resulting in a total generation of 345KW. Voltage profiles and power flow through lines are shown in Figs V&VI respectively. Amount of power fed to the utility grid can be seen under two operating conditions. Summary of the results is presented in Table IV.

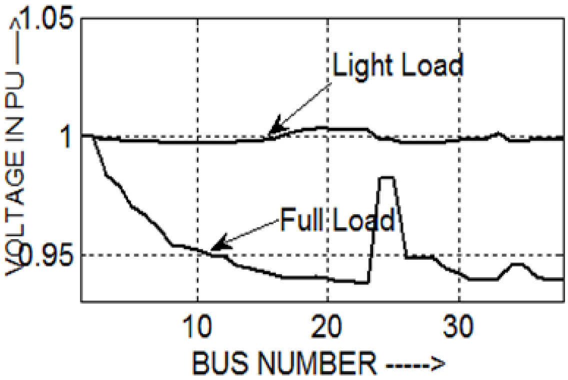

Fig V. Voltage profile of the network under two load conditions

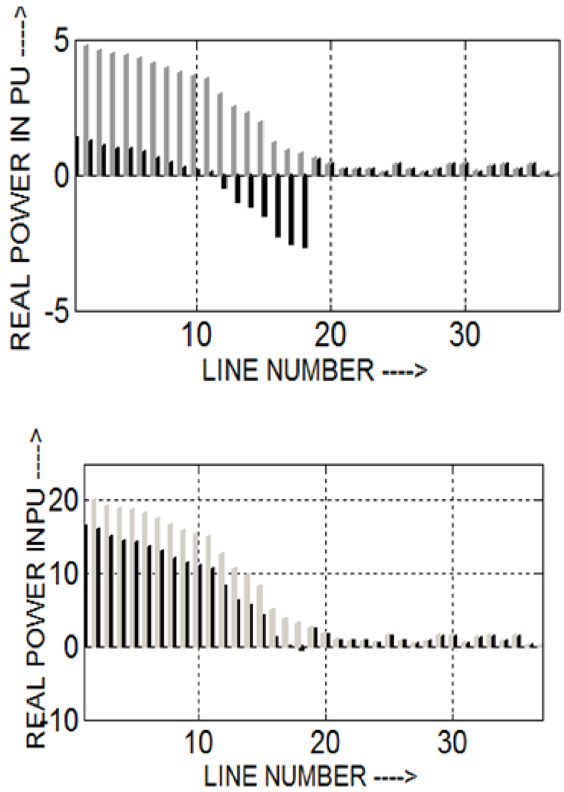

Fig VI. Power flow through lines under light load and full load conditions

It is observed during heavily loaded conditions that the operating PF at the substation falls below 0.6 as the photo voltaic plants are intended to meet only real power demand of the system. Hence, for full load condition, the performance calculations are made by connecting fixed capacitor banks at points where the solar photo voltaic plants are connected so that a considerable amount of reactive power is compensated. The results shown are with an additional capacitor bank of 10KVAr at each photo voltaic plant at LV side so as to maintain grid power factor.

Table IV. Summary after installing SPVS of small capacity at each load point under one DT

Loading condition	Real Power loss(KW)	Percentage Improvement in real loss	Vmin	Substation Bus current Pu	Power drawn from utility grid KW
Light Load	2.46	68.46	0.9975	1.3761	137.36
Full load	79.76	43.28	0.9381	18.1288	1648.26

Total investment required to place the solar photo voltaic panels of 345KW on one distribution transformer along low voltage network may be Rupees 4.14 crores. Considering 300 sunny days a year and an average of 4.5 hours a day annual power generation would be 4,65,750 units. At the rate of Rupees 15 per unit, pay back period works out to be around 6 years.

4.2 Capacity of SPVPs as Percentage of Load on DT

Further analysis is done by compensating some percentage of loads under each distribution transformer of 11KV network simultaneously at full load condition. Results are tabulated in Table V. Fig VII shows the network voltage profile with different percentages of compensation. When the operating power factor at various percentages of compensation has gone below 0.5, fixed capacitors of 25KVAr were installed at each DT to maintain grid Power factor and then analyzed.

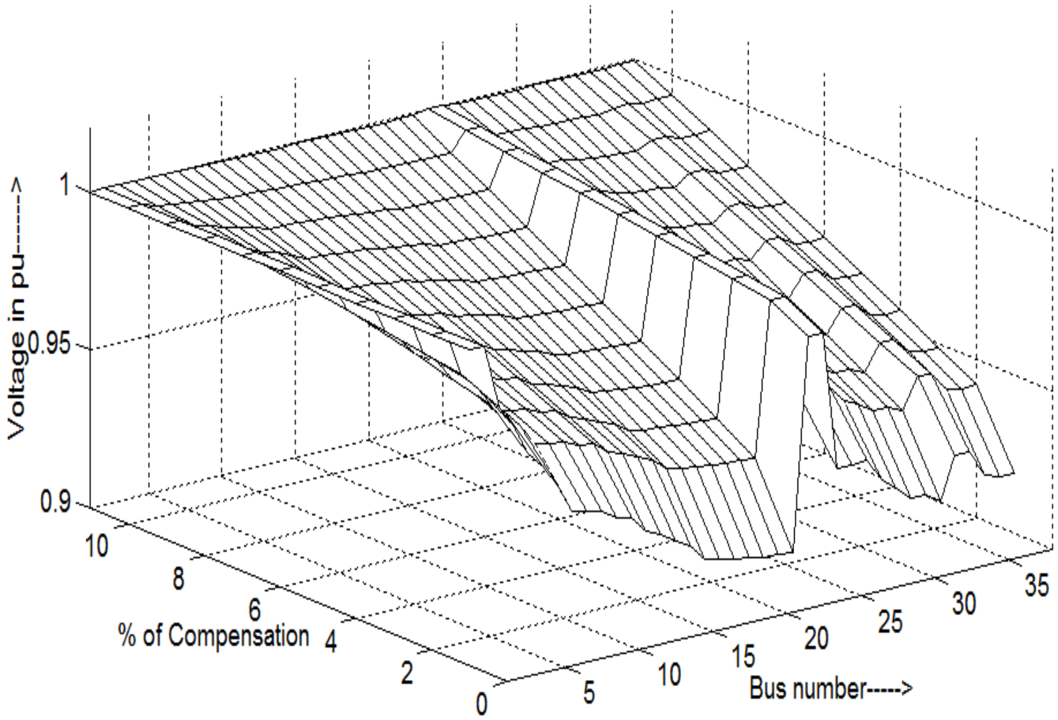

Fig VII. Voltage profile of the network with different compensation.

Table V: Summery After Compensating Some Percent of Load through SPVPs

S. No.	Rating of SPVPs as Percentage of load	Real power loss in KW	Percentage improvement	Minimum voltage	Substation Bus current pu	Power drawn from utility grid KW	Investment In crores
1	0	140.61	--	0.9108	22.8975	2059.34	--
2	10	88.32	37.18	0.9358	18.1589	1815.22	2.232
3	20	68.91	50.99	0.9432	16.0442	1603.93	4.464
4	30	52.11	62.94	0.9506	13.9561	1395.27	6.696
5	40	37.84	73.09	0.9578	11.8929	1189.06	8.928
6	50	25.99	81.51	0.9649	9.8552	985.37	11.160
7	60	16.48	88.28	0.9719	7.8409	783.99	13.392
8	70	9.21	93.45	0.9788	5.8492	584.85	15.624
9	80	4.11	97.08	0.9857	3.8786	387.81	17.856
10	90	1.11	99.22	0.9924	1.9303	192.97	20.088
11	100	0.11	99.92	0.9991	0.0437	0.11	22.320

5. CONCLUSIONS

Solar power would definitely be a right option in agricultural sector which suffers from frequent power outages in the tropical India. It may also offer the possibility of creating micro grids to cater the requirements of a group in the region selected. Availability of required land for placing the panels also strengthens this choice. It is known fact that Solar PV is a costly alternative as of now. Losses only till distribution level in subject feeder are considered in above discussion. In general if we look at the total losses from generation to distribution, the same will be further more. If solar generation is planned in the rural feeders it not only improves grid profile but also reduces losses. There is considerable saving in terms of power and hence capital subsidy also may be considered by government. Also poor voltage regulation and enormous subsidies pumped into this sector necessitates rural generation from long term perspective.

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APPENDIX – I

LINE AND LOAD DETAILS OF THE TEST SYSTEM

Line No.	From Bus	To Bus	R (Ω)	X (Ω)	Load at receiving end bus	
					Real power (KW)	Reactive Power (KVAr)
1	1	2	0.006545	0.00334	45.36	21.97
2	2	3	0.98175	0.501	0	0
3	3	4	0.32725	0.167	45.36	21.97
4	4	5	0.5236	0.2672	10.8	5.23
5	5	6	0.2618	0.1336	45.36	21.97
6	6	7	0.3927	0.2004	72	34.87
7	7	8	0.5236	0.2672	72	34.87
8	8	9	0.06545	0.0334	72	34.87
9	9	10	0.06545	0.0334	45.36	21.97
10	10	11	0.19635	0.1002	36	17.43
11	11	12	0.06545	0.0334	45.36	21.97
12	12	13	0.3927	0.2004	54	26.15

13	13	14	0.19635	0.1002	0	0
14	14	15	0.32725	0.167	0	0
15	15	16	0.32725	0.167	11.52	5.58
16	16	17	0.98175	0.501	0	0
17	17	18	0.3927	0.2004	45.36	21.97
18	18	19	0.2618	0.1336	72	34.87
19	19	20	0.32725	0.167	72	34.87
20	20	21	0.5236	0.2672	72	34.87
21	21	22	0.45815	0.2338	10.8	5.23
22	22	23	0.58905	0.3006	72	34.87
23	3	24	1.4399	0.7348	32.4	15.69
24	24	25	0.06545	0.0334	45.36	21.97
25	12	26	0.32725	0.167	72	34.87
26	26	27	0.06545	0.0334	10.8	5.23
27	12	28	0.32725	0.167	36	17.43
28	14	29	0.32725	0.167	72	34.87
29	15	30	0.32725	0.167	144	69.74
30	16	31	1.309	0.668	72	34.87
31	31	32	0.1309	0.0668	45.36	21.97
32	17	33	0.06545	0.0334	117.36	56.84
33	13	34	0.06545	0.0334	72	34.87
34	34	35	0.19635	0.1002	72	34.87
35	16	36	0.1309	0.0668	144	69.74
36	31	37	0.1309	0.0668	11.52	5.58
37	37	38	0.1309	0.0668	11.52	5.58