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Effect of DC/DC Losses on Optimal Power Flow in Multi-Terminal HVDC

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Abstract: ***This paper presents an optimal power flow for multi-terminal High voltage Direct current system (MT-HVDC) based on Genetic algorithm by using MATLAB R2018a, the results show the big effect of DC/DC losses on OPF and made a comparison between OPF with DC/DC converter losses and without considering this losses. The paper shows the effect of DC/DC converter losses on total fuel cost and transmission line losses, The voltage deviation is shown in result. In this paper IEEE 30 Bus system take as a case study with modified DC generation system connect on Bus number 11 and 13 with two AC/DC and one DC/DC converters in addition to two separate DC generators which can be PV power plants.***

Keywords: HVDC, Optimal power flow, MTDC, DC/DC converter losses, IEEE30 bus system, AC/DC converters

1. Introduction

High voltage direct current transmission (HVDC) is a studied technology that allows power transmission for long distances with low power losses and the interconnection between different frequencies networks. The most common HVDC configuration point to point comprises two converter stations connected by transmission power lines overhead line or undersea cables. Nevertheless, modern power systems may need meshed DC networks for applications such as Super Grids [1] and offshore wind farms [2]. This type of DC grids, called Multi-terminal HVDC systems (MTDC), is viable due to the development of high-power force-commutated semiconductor devices and DC breakers in addition to power converters [3]. Now a day, studies have demonstrated that a densely meshed (MTDC) grid provides advantages in terms of efficiency and security. However, these grids are more difficult to operation and control than conventional point-to-point lines. They require a reliable communication between terminals and optimization algorithms to get the best operating point. In addition, highly meshed MTDC systems require DC/DC stations to interconnect HVDC systems with different configuration or different voltages (e.g monopolar, bipolar) In addition to AC/DC converters to connect MTDC terminals with HVAC systems. DC/DC converters can control active power on a particular HVDC line and limit current in the MTDC during disturbances such as DC faults. So, the classic methodologies for power system operation such as the optimal power flow (OPF) must be adapted to this new case to take converters losses in its considerations. Just like its counterpart AC [4], the optimal power flow for multi-terminal HVDC systems similarly to conventional is a non-linear and non-convex optimization problem. This constitutes challenges in both theory and practice. The degree of complexity is increased when DC/DC converters are included in the model since they involve additional controlled variables as well as non-linear equations related to power losses. Non-convex problems such as OPF lead to local optimums (i.e an optimum within a neighboring set of candidate solutions), in contrast, to convex optimization problems which allow to find the optimum among all possible candidates [5].

The control of HVDC has been discussed in a number of works [6 -10]. By controlling the HVDC system, Some of the most important requirements should be achieved, these are; 1)symmetrical firing of the valve to reduce the abnormal harmonics generated by the converter, 2) keeping the power factor as high as possible, therefore minimizing the reactive volt-ampere consumption in the converter, 3) controlling the DC line current to transmit power with sufficient speed and accuracy of response, 4) protecting inverter operation from commutation failures, 5) providing continuous operating range from full rectification to full inversion, 6) allowing smooth transition from current control to extinction angle control.

Previous papers [11,14] have considered a modified bridge circuit for use in HVDC converter. By including a ‘by-pass valve’ using either additional thyristors or GTO thyristors the reactive volt-ampere absorption and the harmonic generation may be reduced.

Genetic algorithms offers a new and powerful approach to optimize problems made possible by the increasing availability of high performance computers. This algorithm have recently found extensive applications in solving global optimization searching problems when the closed-form optimization technique cannot be applied. Genetic algorithms are parallel and global search techniques that emulate natural genetic operators. The GA is more likely to converge toward the global solution because it, simultaneously, evaluates many points in the parameter space. The method is not sensitive to the starting points and capable to determining the global optimum solution to the OPF for range of constraints and objective functions. In this paper, a simple genetic algorithm is applied to the problem of optimal power flow in MT-HVDC.

2. Multiterminal HVDC Systems

An MT-HVDC is an efficient for applications such as super grids, offshore wind energy and urban distribution systems in high dense areas of the city. This technology allows cost and loss reduction and enhances reliability and security. HVDC systems can be classified according to the type of semiconductor. There are two main semiconductor

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technologies used in HVDC system, namely line and force commutation. Where the line commutation is used for the line-commutated converters (LCC), also called current source converters (CSC), while the second one is more common, used for the voltage source converters (VSC) and the modular multilevel converters (MMC).

For multiterminal HVDC systems [15], today consensus among the scientific community is that VSC and specially MMC are the most prominent technologies for multiterminal grids [16]. One of the main components of an MT-DC system is the AC/DC converter (Rectifiers) which integrates the DC grid with the neighbor AC network(s). Each converter injects or consumes power from the MT-DC grid and controls two variables independently. This is a key feature given by the forced commutation technology. Hence, different operation modes can be obtained. Most of converters in MT-HVDC systems control one variable in the DC side and one variable in the AC side. Usually a terminal controls the power factor in the AC side and the voltage or the power in the DC side. Notwithstanding its high controlability, AC/DC terminals are nodal devices from the point of view of the MT-HVDC grid. This means, power injection but not power flow is controlled in each line. For this reason, it is expected future MT-HVDC systems include DC/DC converters among some branches in order to enhance controllability.

3. Modelling DC/DC Converters

DC/DC converters are relevant for MT-DC system so they allow to control the DC power through branches. There are different topologies of DC/DC converters, most of them are high power devices and require a coupling transformer in order to grant galvanic isolation [13].

Losses in this type of converters, as a forced commutated converter, are classified in conduction losses and switching losses. Both are big dependent of the intrinsic characteristics of the semiconductor devices and passive elements as well as operative variables such as the switching frequency and the type of modulation. For this study the total losses are assumed to be quadratic related to the power transferred. This assumption is based on the results presented by Zhou in [15]. Losses are modeled for two loads *S1* and *S2* with

$$S_1 = \frac{1}{2}.(\alpha + \beta\,.\|q_1\| + \gamma\,.\|q_1\|^2) \quad (1)$$

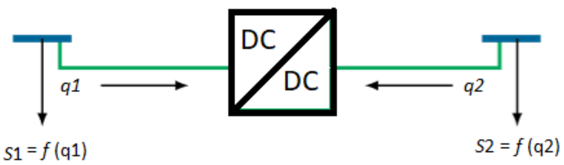

Figure 1: DC/DC converter losses configuration

4. Modelling AC/DC Converters

Almost all HVDC converters are inherently bi-directional; they can convert either from AC to DC (*rectification*) or from DC to AC (*inversion*). A complete HVDC system always includes at least one converter operating as a *rectifier* (converting AC to DC) and at least one operating as an *inverter* (converting DC to AC). An ideal VSC converter transfers the active power it receives on the AC side to its DC side. A non-ideal converter has losses that will make the transmitted power less than the one that is entering the converter.

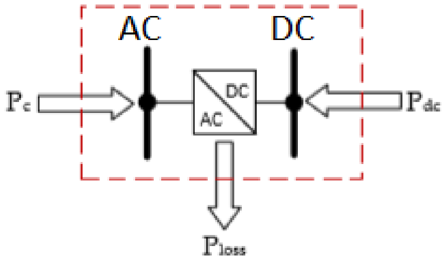

Figure 2: AC/DC losses configuration

$$P_{loss} = k_0 + k_1 I_c + K_2\, I_c^{\,2} \quad (2)$$

$$I_c = \frac{\sqrt{P_c^{\,2} + Q_c^{\,2}}}{\sqrt{2}\, U_c} \quad (3)$$

and the loss coefficients K0 = 11.0331×10−3, K1 = 3.464×10−3 and K2 = 5.5335×10−3 (all p.u.) are taken from [16].

5. Optimal Power Flow

Optimal Power flow (OPF) is allocating loads to plants for minimum cost while meeting the network constraints. It is formulated as an optimization problem of minimizing the total fuel cost of all committed plant while meeting the network (power flow) constraints. The variants of the problems are numerous which model the objective and the constraints in different ways.

The basic OPF problem can described mathematically as a minimization of problem of minimizing the total fuel cost of all committed plants subject to the constraints.

$$Minmize \sum_{i=1}^{n} F_i(P_i) \quad (4)$$

F is the fuel cost equation of the 'i'th plant. It is the variation of fuel cost with generated power (MW).Normally it is expressed as continuous quadratic equation.

$$F_i(P_i) = a_i P_i^{\,2} + b_i P_i + c_i\,, \quad P_i^{min} \le P_i \le P_i^{max} \quad (5)$$

The total generation should meet the total demand and transmission loss. The transmission loss can be determined from power flow.

$$\sum_{i=1}^{n} P_i = D + P_l \quad (6)$$

$$P_i = real\left(\sum_{j}^{n} V_i\, Y_{ij}^{*}\, V_j\right), i = 1,2,..n \quad (7)$$

$$Q_i = imag\left(\sum_{j}^{n} V_i\, Y_{ij}^{*}\, V_j\right), i = 1,2,..n \quad (8)$$

6. Genetic Algorithm

Genetic algorithms are a type of optimization algorithm, meaning they are used to find the maximum or minimum of a function.

Genetic algorithms are a type of optimization algorithm, meaning they are used to find the optimal solution(s) to a given computational problem that maximizes or minimizes a particular function. Genetic algorithms represent one branch of the field of study called evolutionary computation [2].in that they imitate the biological processes of reproduction and natural selection to solve for the 'fittest' solutions [17]. Like in evolution, many of a genetic algorithm's processes are random, however this optimization technique allows one to set the level of randomization and the level of control [17]. These algorithms are far more powerful and efficient than random search and exhaustive search algorithms [2], yet require no extra information about the given problem. This feature allows them to find solutions to problems that other optimization methods cannot handle due to a lack of continuity, derivatives, linearity, or other features.

7. Results

The proposed models were tested using a modified version of IEEE 30 Bus test system depicted in Fig 3. It consists of 30 nodes AC, 41 AC lines, two terminals AC/DC and one DC/DC converter. Hence, it covers a wide range of components present in an MT-HVDC system. The parameters used in this simulation shown in the appendix in the end of this paper.

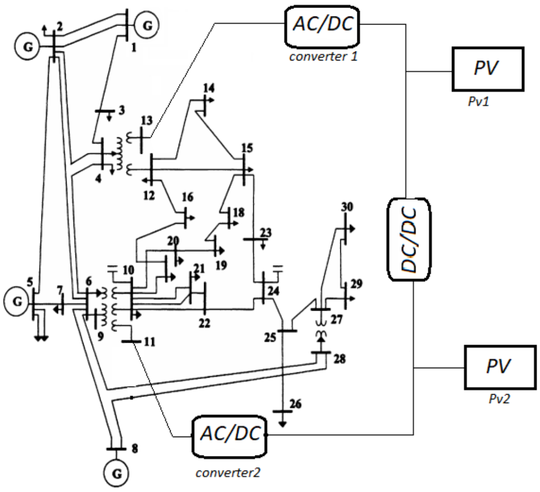

Figure 3: Modified system to test MTDC

The data is on 100 MVA base. For all analysis on this system Vmin, Vmax, Φ min, and Φ max for bus i are considered to be 0.9 p.u, 1 .I p.u., -45 degree and 45 degree respectively. Based on these results, it could be shown that the DC/DC and AC/DC converter losses effect on OPF. However, further research is required to generalize these results. The comparison between the results on Modified MT-HVDC system with/without DC/DC converter losses is shown in figure4.

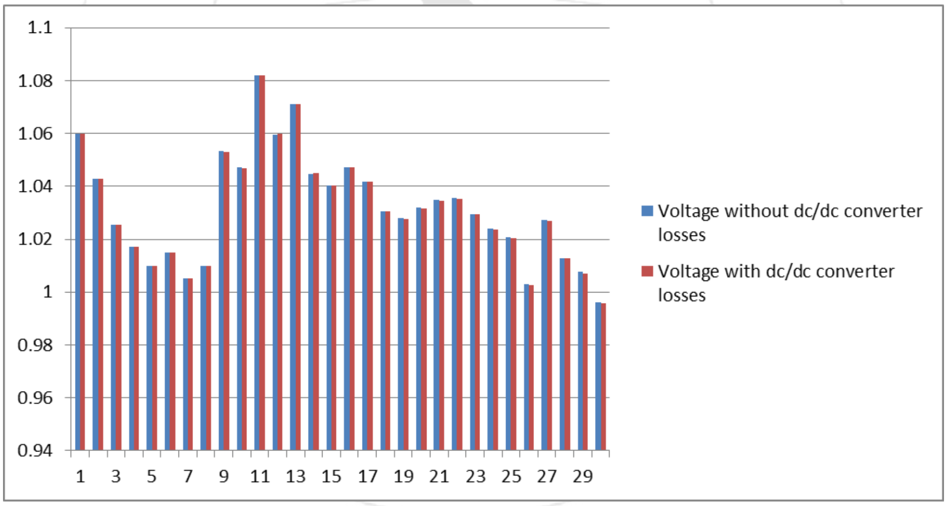

Figure 4: Bus Voltages

Figure 5 can shows the effect of DC/DC losses on power generation where the power of DC1 and DC2 are decrease when DC/DC losses considered, in each case AC/DC converters losses was considered and it was 2.20001 MW where the total AC/DC and DC/DC converter losses in second case was 2.2229 MW.

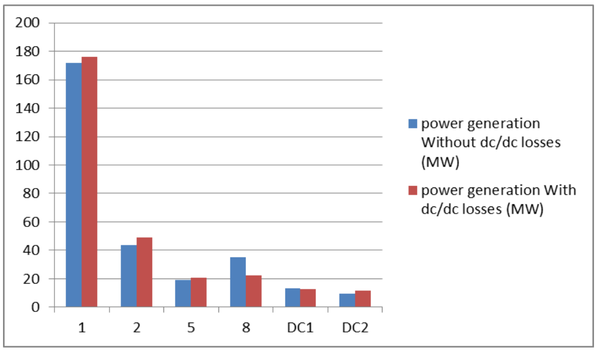

Figure 5: Power Generation

Finally the overall fuel cost is increase from 804.5602 to 801.8792 and the transmission line losses from 8.8477 to 9.3516 MW.

8. Conclusion

From the results the effect of DC/DC converter losses is shown mainly on total losses and optimal generation cost. If dc/dc converter losses considered the generation cost is smaller than when dc/dc converter losses ignored, the deviation on each bus voltage is shown in previous section. So considering DC/DC converter losses is essential and important to achieve good result in Optimal Power Flow in Multi-Terminal High Voltage Direct Current (MT-HVDC) systems, so it is not acceptable to ignore DC/DC losses in optimal power flow analysis when the system contains large number of converters.

The effect of one DC/DC converter losses on the overall fuel cost increases from 801.8792 to 804.5602 which is equal to 0.33%, and the transmission losses increase by 5.3 %, so the high negative effect of DC/DC converter losses on each total fuel cost and transmission line losses is proven in this paper.

References

[1] D. V. Hertem and M. Ghandhari, "Multi-terminal vsc-hvdc for the european supergrid: Obstacles," Renewable and Sustainable Energy Reviews, Vol. 14, No. 9 2010, pp. 3156 – 3163,
[2] T. Haileselassie and K. Uhlen, "Power system security in a meshed north sea hvdc grid," Proc. of the IEEE, Vol. 101, No. 4, 2013, pp. 978–990..
[3] W. Wang, M. Barnes, O. Marjanovic, and O. Cwikowski, "Impact of dc breaker systems on multiterminal vsc-hvdc stability," IEEE Tran. On Power Delivery, Vol. PP, no. 99, pp. 1–1, 2015.
[4] W. Leterme, P. Tielens, S. De Boeck, and D. Van Hertem, "Overview of grounding and configuration options for meshed hvdc grids," IEEE Tran. On Power Delivery., Vol. 29, No. 6, 2014, pp. 2467–2475.
[5] Y. Zhou, D. Macpherson, W. Blewitt, and D. Jovcic, "Comparison of dc-dc converter topologies for offshore wind-farm application," in Power Electronics, Machines and Drives (PEMD 2012), 6th IET International Conference on, March 2012, pp. 1–6.
[6] H. D. Al-Majali, Voltage control of modified series-connected HVDC bridges, Electric Power Systems Research (Elsevier), Vol.43, 1997, 37-44.
[7] H. D. Al-Majali, Voltage control of series-connected modified HVDC bridgesusing GTO thyristor by-pass valves, , Electric Power Systems Research (Elsevier) Vol.49, No.2, 1999, 79-86.
[8] H. D. Al-Majali and B. H Al-Majali, **"**Reduced Harmonics generated of HVDC Converter Using By-Pass Valves" Transaction on Power Systems, (WSEAS), Vol.10, 2015
[9] H. D. Al-Majali and S. Al-Dhalaan, "Transient of Modified HVDC Converter", Electric Power Systems Research (Elsevier), Vol.77, No. 10, 2007, PP. 1329 – 1336.
[10] H. D. Al-Majali, "Abnormal Harmonics Generated by Modified HVDC Converters" Electric Power Components and Systems (Taylor & Francis). Vol.35, No.6, 2006, PP 639 – 654.
[11] H. D. Al-Majali and D. O'Kelly, "Control of an HVDC Converter Using GTO Thyristor By-Pass Valves", 26th UPEC, Brighton Polytechnic, U.K, 1991, PP 36-39.
[12] H. D. Al-Majali and D. O'Kelly, "Control of an HVDC Converter Using By-Pass Valves", 25th UPEC, Robert Gordon's Institute of Technology, Aberdeen, U.K, 1990. PP 652-656.
[13] H. D. Al-Majali and B. H. Al-Majali, " Control of AC/DC Converter Under Unbalanced System Conditions", Jordan Journal of Electrical Engineering (JJEE), Vol.1, No.1, 2015, pp 25 -36.
[14] H. D. Al-Majali and S. Al-Dhalaan, "A Snubber Configuration for Modified Bridge Converter" Electric Power Components and Systems (Taylor & Francis) Vol.34, No.11, 2006, PP. 1177-1190.
[15] J. Beerten, S. Cole, and R. Belmans. A sequential AC/DC power flow algorithm for networks containing Multi-terminal VSC HVDC systems. In IEEE Power and Energy Society General Meeting, pages 1–7, July 2010.
[16] Goldberg, D. E. (1989). Genetic Algorithms in Search, Optimization, and Machine Learning. Reading: Addison-Wesley.
[17] Goldberg, D. E. (1989). Genetic Algorithms in Search, Optimization, and Machine Learning. Reading: Addison-Wesley.

Appendix

Modified IEEE30 Bus system
This modification add two AC/DC terminal and HVDC-network to provide MTDC with original AC network, The single line diagram shows in figure R1.

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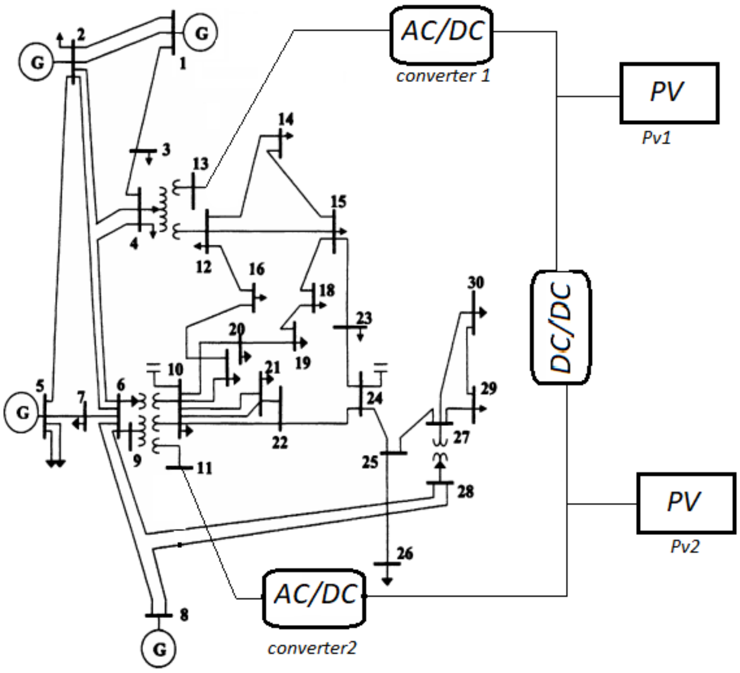

Figure R1: Single line diagram of Modified system

System Data shows in tables R1,R2and R3.

Table R1: Generators parameters

G. No	P max MW	P min MW	Q min Mvar	Q max Mvar	Ai	Bi	ci
1	50	200	-	-	0.00375	2	0
2	20	80	-20	100	0.0175	1.75	0
3	15	50	-15	80	0.0625	1	0
4	10	35	-15	60	0.00834	3.25	0
Pv1	10	30	-	-	0.025	3	0
Pv2	10	30	-	-	0.025	3	0

Table R2: Bus data

Bus No.	$P_{G,i}$	$P_{D,i}$	$Q_{D,i}$	V_i	V_i^{max}	V_i^{min}	Base KV
1	0.9920	0.0000	0.0000	1.0600	1.10	0.90	132
2	0.8000	0.2170	0.1270	1.0430	1.10	0.90	132
3	0.0000	0.0240	0.0120	1.0000	1.05	0.95	132
4	0.0000	0.0760	0.0160	1.0000	1.05	0.95	132
5	0.5000	0.9420	0.1900	1.0100	1.10	0.90	132
6	0.0000	0.0000	0.0000	1.0000	1.05	0.95	132
7	0.0000	0.2280	0.1090	1.0000	1.05	0.95	132
8	0.2000	0.3000	0.3000	1.0100	1.10	0.90	132
9	0.0000	0.0000	0.0000	1.0000	1.05	0.95	1
10	0.0000	0.0580	0.0200	1.0000	1.05	0.95	33
11	0.2000	0.0000	0.0000	1.0820	1.10	0.90	11
12	0.0000	0.1120	0.0750	1.0000	1.05	0.95	33
13	0.2000	0.0000	0.0000	1.0710	1.10	0.90	11
14	0.0000	0.0620	0.0160	1.0000	1.05	0.95	33
15	0.0000	0.0820	0.0250	1.0000	1.05	0.95	33
16	0.0000	0.0350	0.0180	1.0000	1.05	0.95	33
17	0.0000	0.0900	0.0580	1.0000	1.05	0.95	33
18	0.0000	0.0320	0.0090	1.0000	1.05	0.95	33
19	0.0000	0.0950	0.0340	1.0000	1.05	0.95	33
20	0.0000	0.0220	0.0070	1.0000	1.05	0.95	33
21	0.0000	0.1750	0.1120	1.0000	1.05	0.95	33
22	0.0000	0.0000	0.0000	1.0000	1.05	0.95	33
23	0.0000	0.0320	0.0160	1.0000	1.05	0.95	33
24	0.0000	0.0870	0.0670	1.0000	1.05	0.95	33
25	0.0000	0.0000	0.0000	1.0000	1.05	0.95	33
26	0.0000	0.0350	0.0230	1.0000	1.05	0.95	33
27	0.0000	0.0000	0.0000	1.0000	1.05	0.95	33
28	0.0000	0.0000	0.0000	1.0000	1.05	0.95	132
29	0.0000	0.0240	0.0090	1.0000	1.05	0.95	33
30	0.0000	0.1060	0.0190	1.0000	1.05	0.95	33

Table R3: Lines Data

Line No.	From Bus No.	To Bus No.	R	X	B_{ch} (Full)	Max. Line Rating
1	1	2	0.0192	0.0575	0.0528	99.00
2	1	3	0.0452	0.1652	0.0408	99.00
3	2	4	0.0570	0.1737	0.0368	99.00
4	3	4	0.0132	0.0379	0.0084	99.00
5	2	5	0.0472	0.1983	0.0418	99.00
6	2	6	0.0581	0.1763	0.0374	99.00
7	4	6	0.0119	0.0414	0.0090	99.00
8	5	7	0.0460	0.1160	0.0204	99.00
9	6	7	0.0267	0.0820	0.0170	99.00
10	6	8	0.0120	0.0420	0.0090	99.00
11	6	9	0.0000	0.2080	0.0000	99.00
12	6	10	0.0000	0.5560	0.0000	99.00
13	9	11	0.0000	0.2080	0.0000	99.00
14	9	10	0.0000	0.1100	0.0000	99.00
15	4	12	0.0000	0.2560	0.0000	99.00
16	12	13	0.0000	0.1400	0.0000	99.00
17	12	14	0.1231	0.2559	0.0000	99.00
18	12	15	0.0662	0.1304	0.0000	99.00
19	12	16	0.0945	0.1987	0.0000	99.00
20	14	15	0.2210	0.1997	0.0000	99.00
21	16	17	0.0524	0.1923	0.0000	99.00
22	15	18	0.1073	0.2185	0.0000	99.00
23	18	19	0.0639	0.1292	0.0000	99.00
24	19	20	0.0340	0.0680	0.0000	99.00
25	10	20	0.0936	0.2090	0.0000	99.00
26	10	17	0.0324	0.0845	0.0000	99.00
27	10	21	0.0348	0.0749	0.0000	99.00
28	10	22	0.0727	0.1499	0.0000	99.00
29	21	22	0.0116	0.0236	0.0000	99.00
30	15	23	0.1000	0.2020	0.0000	99.00
31	22	24	0.1150	0.1790	0.0000	99.00
32	23	24	0.1320	0.2700	0.0000	99.00
33	24	25	0.1885	0.3292	0.0000	99.00
34	25	26	0.2544	0.3800	0.0000	99.00
35	25	27	0.1093	0.2087	0.0000	99.00
36	28	27	0.0000	0.3960	0.0000	99.00
37	27	29	0.2198	0.4153	0.0000	99.00
38	27	30	0.3202	0.6027	0.0000	99.00
39	29	30	0.2399	0.4533	0.0000	99.00
40	8	28	0.0636	0.2000	0.0428	99.00
41	6	28	0.0169	0.0599	0.0130	99.00