Onshore wind farm - Reliability centered cable routing

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Abstract

Designing an onshore wind farm is a complex planning process that requires various stages to be completed. The prime focus of this work is to assist planners and experts in finding the optimal cable layout of the onshore wind farm. The optimization algorithm is designed using mixed integer linear programming (MILP). The MILP algorithm takes into account system reliability, power transfer capacities and power quality issue. The novelty in this optimization algorithm is to simultaneously minimize cable installation cost and the cost of lost energy production and therefore maximize the reliability of the system. Additionally, the algorithm supports the optimal selection among different cable options, with different features, prices and capacities. By calculating voltage drop at the point of connection (POC), power quality issue is considered as well. The designed algorithm provides optimal results for four different wind farm layouts. Every layout is tested for three different case scenarios, where different number and type of cables are considered. The results show that more cable options contribute in lowering the total costs. Moreover, cables with higher capacity can help in improving the power quality issue.

1. Introduction

Wind energy has attracted a lot of attention and investments in the last decades. It has been shown that wind farms can yield a great potential of wind energy resources, their negative environmental impact is negligible, construction time short, and they have the shortest period of investment return in comparison with other renewables [1].

However, the design of the wind farm is a complex task. It requires a large set of variables to be taken into account and decisions to be made. Nevertheless, the fundamental aim of every wind farm design is to maximize energy production, minimize capital and operating costs, and stay within the constraints imposed by the site [2]. These constraints are usually associated with maximum installed capacity, site boundaries (such as road, dwellings, etc.), environmental, noise and visual issues, turbine minimum spacing, communication signals.

According to [3], the four main steps in the design of a wind farm are: selecting the right site, optimizing the location of each turbine, establishing the infrastructure and connecting the farm to the existing electrical grid.

Assuming that the site and the best turbine positions have been identified, different papers focused on finding the optimal cable connection among turbines, while minimizing the total cable cost. For example, in [3], [4], [5], [6], [7] and [8] the same authors focus on improving their algorithm for optimal cable layout within an offshore wind farm. They use a mixed integer linear programming (MILP) in order to solve the inter-array cable routing problem. The original version of this problem consists of connecting all the offshore turbines to one (or more) offshore substation(s), minimizing the total cable cost. However, they gradually include a number of constraints: the energy leaving a turbine must be supported by a single cable; the maximum energy flow (when all the turbines produce their maximum) in each connection cannot exceed the capacity of the installed cable; different cables, with different capacities and costs can be installed; cable crossing must be avoided; a given maximum number of cables can be connected to each substation; cable losses (dependent on the cable type, the cable length and the current flow through the cable) must be considered. In their model installing the cable with different capacity is based on how many turbines can the cable support (e.g. cable 1 supports three turbines at a cost of 393 €/m while cable 2 supports five turbines at a cost of 540 €/m). Similar cable capacity constraint is presented in [9] where 2 types of cables are considered: one supporting 5 wind turbines and the other 8. The aim of the optimization in [9] is to find the minimum cost array cable layout in the offshore wind farm. The optimization is implemented through a hop-indexed integer programming, together with a developed heuristic for computing layouts, which is based on the savings heuristic
for vehicle routing. In [10], a fast heuristic specifically designed for wind farm cable routing problem is presented. This heuristic iteratively improves a cable layout by finding and canceling negative cycles in a suitably defined network. The authors argue that this algorithm gives better solutions on large wind farms compared to a MILP solver. However, on small to medium instances the MILP solver performs better in terms of solution quality.

What the above studies have missed to identify is the power quality issue. Namely, the interconnection of the onshore wind farm to the distribution grid is often regarded as a potential source of power quality disturbances. Thus, regardless of the distribution network configuration, it is very important to investigate the influence of renewables scheduled to be connected to the distribution network and to ensure a required power quality [1].

The framework of technical criteria and requirements when connecting distributed generation to the MV distribution grid is presented in [11], together with the description of different power quality issues, such as slow (steady-state) voltage variations, fast voltage changes, flicker and harmonic emissions. According to [12], by calculating steady-state voltage variation, it is possible to determine the state or the condition of the distribution system, i.e. is it weak or strong enough to accommodate the new source of power (wind generator).

The expected power quality disturbances are usually calculated at the Point of Common Coupling (PCC). PCC is the point at which the effect of the wind farm on the electricity network should be determined [2]. Quite often PCC coincides with the Point of Connection (POC). POC is the point at which responsibility for ownership and operation of the electrical system passes from the wind farm to the electricity network operator [2]. In this paper it is assumed that PCC and POC coincide.

This paper aims to find the optimal cable layout for an onshore wind farm using MILP approach. However, compared to previous studies, the novelty in this algorithm is the reliability assessment of the wind farm. Beside minimizing cable installation cost, the algorithm aims to minimize the cost of lost energy production as well. Cost of lost energy production reflects the impacts of interruption duration, failure rate of the wind turbine, as well as the cost of lost kWh produced by the wind turbine [13]. In the proposed optimization model, cost of lost energy production is the measure of reliability, since it is directly linked to the proposed layout. Based on the suggested outline of the network, the failure rate as well as the cost of lost energy production for every wind turbine within the farm is updated. The algorithm also takes into account the possibility of installing cables with different capacities and different costs. However, these capacities are based on the maximum current that the cable can withstand and the voltage level of the network. Additionally, the algorithm tends to assess power quality as well. Namely, slow (steady-state) voltage variation at POC is calculated. This voltage variation happens due to the active power flow on the resistive part of the network impedance and it yields voltage increase at POC (point where wind farm is connected to a distribution network) [11]. To analyze the effectiveness of the algorithm, four different possible positions of POC are considered. The developed method have been tested on an actual distribution model including a wind farm and results are discussed.

This paper is structured as follows: Proposed optimization model is formulated in Section 2. Section 3 reviews the onshore wind farm and presents simulation results. The last section concludes the work.

2. Proposed formulation

Assuming that the wind farm site and the best positions of wind turbines (WTS) have been identified, the optimization model focuses on finding the optimal cable connections among turbines, with the aim to minimize the total cost and maximize the reliability. The optimization is formulated as mixed integer linear programming (MILP).

The main optimization objective is to minimize the total cost which is comprised of cable installation cost and cost of lost energy production, as formulated in (1).

\[
\min_{\lambda(i,j)} \left( C^{CIC} + C^{LEC} \right) \tag{1}
\]

Cable installation cost \( C^{CIC} \) is associated with the construction of the potential cable between nodes \( i \) and \( j \).

\[
C^{CIC} = \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{c=1}^{C} \lambda(i,j) C_{c} d(i,j) sf
\]

(2)

Cost of lost energy production \( C^{LEC} \) reflects the impacts of interruption duration, failure rate of wind turbine, as well as the cost of lost kWh produced by the wind turbine [13]. In the proposed optimization model, cost of lost energy production is the measure of reliability, since it is
directly linked to the proposed configuration. Based on the suggested outline of the wind farm, the failure rate as well as the cost of lost energy production for every node is updated.

\[ C_{\text{LEC}} = \frac{1}{1 + dr} \sum_{i=1}^{T} \sum_{c=1}^{N} \lambda_c(i) \cdot P(i) \cdot et(i) \cdot r(i) \cdot f(i) \]  

(3)

In this model, more than one cable option is possible. That is, based on the cable’s capacity, optimization proposes an adequate outline. Number of possible cable options is \( C \) \( (C \in \{1, 2, \ldots\}) \). It should be noted that this does not mean that C parallel cables are constructed. Instead, there are C binary decision variables, corresponding to C cables with different costs and capacities, described as follows:

\[ x_c(i, j) = \begin{cases} 1, & \text{if cable } c \text{ is constructed from node } i \text{ to } j \\ 0, & \text{otherwise} \end{cases} \]

(4)

It is important to notice that these binary variables exclude one another, i.e. if one of them is 1, all others are 0 for the same pair of nodes \((i, j)\).

\[ \sum_{c=1}^{C} x_c(i, j) \leq 1 \]

(5)

Initial failure rate \( \lambda_{\text{init}} \) of every node is given. Every wind turbine has its own failure rate \( \lambda_{\text{WT}} \), while the initial failure rate of POC is assumed to be 0.

\[ \lambda_{\text{init}}(i) = \begin{cases} \lambda_{\text{WT}}, & \text{node representing wind turbine} \\ 0, & \text{node representing POC} \end{cases} \]

(6)

Equation (5) describes the failure rate of each node. The algorithm is moving downstream, toward the POC, and it updates the failure rate of every node \( j \) by summing its initial failure rate \( \lambda_{\text{init}}(j) \), failure rate of its upstream nodes \( \lambda_{\text{s}}(i) \) and upstream cables \( \lambda_{\text{c}}(i, j) \). Therefore, every downstream node \( j \) has a higher failure rate than its upstream node \( i \). In the case of fault, all upstream wind turbines from the place of fault will be disconnected; thus, affecting the cost of lost energy. The closer the fault is to the POC, more wind turbines are disconnected and the cost of lost energy is bigger. Consequently, POC yields the highest failure rate.

Failure rate of every cable depends on the distance between nodes \( i \) and \( j \), and it is described by (6).

Since (5) involves the multiplication of binary and continuous variable, this makes the problem nonlinear. In order to solve optimization problem as MILP, a Big M method is used. Based on this method, a nonlinear product of two variables \( z = A \sum_{c=1}^{C} x_c \), where \( A \) is a continuous variable and \( \sum_{c=1}^{C} x_c \) is a sum of binary variables that exclude each other, is linearized by following equations [14]:

\[ z \leq M \sum_{c=1}^{C} x_c \]

(7)

\[ z \leq A \]

(8)

\[ z \geq A - \left(1 - \sum_{c=1}^{C} x_c \right) \cdot M \]

(9)

\[ z \geq 0 \]

(10)

A is bounded below by zero and above by a Big M.

\[ \sum_{c=1}^{C} x_c(i, j) = 0 \]

(11)

\[ \sum_{i=1}^{N} \sum_{c=1}^{C} x_c(i, j) = 1, \forall i \neq \text{POC} \]

(12)

\[ \sum_{i=1}^{C} x_c(i, j) + x_c(j, i) \leq 1, i \neq j \]

(13)

\[ \sum_{i=1}^{N} \sum_{c=1}^{C} x_c(i, \text{POC}) \geq 1 \]

(14)

Equations (11), (12), (13) represent constraints that are ensuring radial supply and hence only one downstream node, without any loops made [15]. Equation (11) ensures that there is no connection leading from and to the same node. In (12) it is assumed that every node (except POC) needs to have only one downstream connection. This paper considers directional connections, meaning that \( x(i, j) \) and \( x(j, i) \) are not the same. If there is a connection from node \( i \) to node \( j \) (i.e. the upstream node), (13) prevents possible connection from \( j \) to \( i \), i.e. creating a loop in the system between nodes \( i \) and \( j \). The POC node is assumed to be capable of receiving the power supply from all WT nodes. The link to the POC, i.e. at least one connection upstream of the POC node, is confirmed by (14).

The power transfer capacity of the cables is calculated according to the following formula:

\[ LC_c = \sqrt{3} Ul_c \]

(15)

where \( U \) denotes the voltage level in the feeders and \( I_c \) denotes the current capacity of the cable \( c \). Therefore, every cable type has its own power transfer capacity.

\[ \sum_{i=1}^{N} LF(i, j) = P(i) + \sum_{i=1}^{N} LF(i, i), \forall i \neq \text{POC} \]

(16)

\[ LF(i, j) \leq \sum_{c=1}^{C} x_c(i, j) \cdot LC_c \cdot 0.5 \]

(17)

Equation (16) represents power balance at node \( i \). In other words, (16) assures that the output power flow from node \( i \) (i.e. the summation of power flow exiting the node \( i \) to the downstream node) \( j \) is equal to the supply at node \( i \) (\( P(i) \)) plus the input power flow to node \( i \) (i.e. the summation of power flow entering the node \( i \) from the upstream node(s) \( i \)). Equation (17), on the other hand, guarantees that the power flow at each line is smaller than the power capacity of the line. As suggested by the utility practice, a safety margin of 50% usability of the current capacity is adopted for normal operating conditions [16].

In order to analyze power quality requirements, the maximum steady-state voltage variation \( \epsilon \) at the POC is evaluated using the following simplified relation [11]:

\[ \epsilon \approx \frac{100}{U^2} \left( R \sum_{i=1}^{N} P(i) + X \sum_{i=1}^{N} Q(i) \right) \]

(18)

\[ R \text{ and } X \text{ are series line resistance and reactance at POC, respectively, and} \]

they depend on the cable type (every cable type \( c \) has its own electrical parameters, \( R_c \) and \( X_c \)).

\[ R = \sum_{i=1}^{N} \sum_{j=1}^{N} \left( \sum_{c=1}^{C} R_c \cdot x_c(i, j) \right) d(i, j) \]

(19)

\[ X = \sum_{i=1}^{N} \sum_{j=1}^{N} \left( \sum_{c=1}^{C} X_c \cdot x_c(i, j) \right) d(i, j) \]

(20)
3. Case study

3.1. Test system

The effectiveness of the MILP approach is tested using an actual onshore wind farm in Sweden. The wind farm consists of 13 wind turbines and 4 possible POCs, which geographical coordinates are known. Based on these coordinates, Euclidean distances between turbines are estimated (Appendix A). To address the real terrain between the turbines, these Euclidean distances are multiplied with a safety factor, $sf$.

According to the utility practice, $sf$ is assumed to be 1.7. Graphical representation of wind turbine layout is presented in Figure 1.

As already explained, taking into consideration the existing wind turbine layout, the idea of this paper is to find the optimal cable layout of the wind farm, while minimizing cable installation cost and cost of lost energy production.

Usually, the turbines are interconnected by a medium voltage (MV) electrical network, in the range 10–35 kV. In most cases this network consists of underground cables, but in some locations overhead lines on wooden poles are adopted [2]. In this model, turbines are interconnected by a 33kV underground cable network. Table 1 presents the typical technical data for the Three Core Armoured Copper Conductors (TM) i7-6600U CPU 2.60GHz with 16GB RAM.

The proposed simulation for MILP is formulated in GAMS software using CPLEX solver and performed in Windows 10, on an Intel (R) Core (TM) i7-6600U CPU 2.60GHz with 16GB RAM.

Table 1

| Cable type | 1 | 2 | 3 |
|------------|---|---|---|
| Nominal cross-sectional area [mm²] | 3x240 | 3x150 | 3x300 |
| R, [Ω/km] (Maximum AC resistance @ 90°C) | 0.0978 | 0.1950 | 0.0788 |
| X, [Ω/km] (Reactance @50Hz) | 0.109 | 0.118 | 0.105 |
| $I_i$ [A] (Continuous current carrying capacity) | 435 | 335 | 490 |
| $Z_i$ [Ω/km] (Price of the cable) | 63 049 | 59 197 | 67 509 |

Table 2

| Cable Type | POC1 | POC2 | POC3 | POC4 |
|------------|------|------|------|------|
| Total Cost [€] | 1 450 377 | 1 504 431 | 1 484 622 | 1 366 965 |
| Cost of Lost Energy [€] | 517 936 | 517 541 | 517 936 | 544 752 |
| Cable Installation Cost [€] | 932 441 | 986 890 | 966 686 | 822 213 |
| Total Cable Length [m] | 8 699 | 9 207 | 9 019 | 7 671 |
| Voltage Increase [%] | 1.908 | 2.02 | 1.978 | 1.683 |

Table 3

| Cable Type | POC1 | POC2 | POC3 | POC4 |
|------------|------|------|------|------|
| Total Cost [€] | 1 420 682 | 1 477 463 | 1 456 870 | 1 322 632 |
| Cost of Lost Energy [€] | 517 936 | 517 541 | 517 936 | 544 752 |
| Cable Installation Cost [€] | 902 746 | 959 922 | 938 934 | 777 880 |
| Total Cable Length [m] | 8 699 | 9 207 | 9 019 | 7 671 |
| Voltage Increase [%] | 2.987 | 2.999 | 2.986 | 3.000 |

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Table 4

| Cable Type | POC1 | POC2 | POC3 | POC4 |
|------------|------|------|------|------|
| Total Cost [€] | 1 411 608 | 1 474 090 | 1 441 192 | 1 319 478 |
| Cost of Lost Energy [€] | 571 660 | 597 953 | 571 660 | 544 436 |
| Cable Installation Cost [€] | 839 948 | 876 137 | 869 531 | 775 042 |
| Total Cable Length [m] | 8 047 | 8 341 | 8 309 | 7 525 |
| Voltage Increase [%] | 2.862 | 2.974 | 2.893 | 2.992 |

Table 2

| Cable Type | POC1 | POC2 | POC3 | POC4 |
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3.1. Test system

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3.2. Simulation results

The simulation includes the comparison of four different wind farm layouts. Each layout has a different point of connection (POC) while the number and positions of wind turbines are fixed. For each possible layout, there are 3 case scenarios depending on the type(s) of cable(s) included in the simulation. First case considers installation of the cable type 1, the second case installation of types 1 and 2, while the third scenario includes types 1, 2 and 3 together. The presented algorithm can easily support even more types of cables. However, in order to efficiently represent the potential of the algorithm, this study focuses on 3 cable types.

The results of compared optimization studies including system reliability, power transfer capacities and power quality for all three cases are presented in Tables 2, 3 and 4. Wind farm outlines proposed by MILP for all 4 layouts under 3 case scenarios are presented in Figures 2a - 4d. The purpose of 4 POCs is to recognize the best possible layout of the wind farm. This is quite beneficial in the planning phase since it helps in lowering the expenses. It can be seen in Figure 5a that in all three cases outline with POC4 gives the lowest total cost. Consequently, cable installation cost and total cable length are the lowest in the layout with POC4 (Figures 5b, 5d).
Fig. 3. Wind Farm Layouts with Cable Type 1&2.

Fig. 4. Wind Farm Layouts with Cable Type 1&2&3.
Configuration for every layout is the same in the first (with cable type 1) and second case scenario (with cable types 1 & 2). However, in the second case, the algorithm seizes the opportunity to install cable type 2 wherever possible, which has lower capacity but it is also cheaper than cable type 1. Therefore, cable installation costs are lower in the second case than in the first. However, since the outline does not change, there are no differences in total cable length and cost of lost energy production.

With the possibility to install cable type 3, which is the most expensive but it has the biggest capacity (third case scenario), the optimization proposes outlines with longer feeders that have the ability to support more turbines. Generally, for every layout, total cable length is the smallest in the third case. However, the cost of lost energy production is higher than in the first two cases for outlines with POC 1, POC 2 and POC 3. Longer feeders increase certain risk - in case the failure happens on a feeder, more turbines on that feeder can be disconnected. However, the layout with POC 4 is almost the same in all three scenarios, and thus, gives very close values of cost of lost energy.

Regarding the power quality issue, in all cases the voltage increase limit at POC is respected. The first case gives the lowest voltage increase. This is due to electrical parameters of the cable type 1. Once the cable type 2 is introduced (with higher resistance and reactance), there is a significant rise in the voltage increase at POC. However, combination with the cable type 3 gives slightly better (lower) values. It can be concluded that cables with higher capacity give better overview when it comes to power quality issues. This can be also confirmed by additional experimental results.

To highlight the comparison between different cable types, two complementary scenarios are considered: installing only cable type 2 and only cable type 3, and they are compared with the first case scenario (installing only cable type 1). By installing only cable type 2, simulation for every layout obtains infeasible results. This means that for the given parameters, one of the constraints can not be satisfied, and that is maintaining the voltage increase below 3%. By omitting the indicated constraint, results presented in Table 5 are obtained (next to every numerical value is a percentage indicator that shows if the obtained value is higher or lower than the value acquired by installing only cable type 1). It can be seen that the power quality is completely violated in this case. Moreover, when comparing total costs with total costs obtained by installing cable type 1, they are on average 2% higher, even though...
Fig. 6. Wind Farm Layouts including “non-cross” constraint.

Fig. 7. Wind Farm Layouts including “non-cross” constraint.
cable type 2 is cheaper than cable type 1. The only improvement with cable type 2 is the cost of lost energy, which is on average 7% lower, and the reason for that is the outline with shorter feeders. Since voltage increase at POC also depends on the rated power and number of wind turbines within a farm, in order to satisfy the power quality constraint in this scenario, the solution could be either to connect less turbines or to consider turbines with smaller rated power. However, the latter option is not viable, since the purpose of this paper is to find optimal cable layout, turbines within a farm, in order to satisfy the power quality constraint in

\[ \sum_{i=1}^{C} (x_c(i,j) + x_c(j,i) + x_c(l,k) + x_c(k,l)) \leq 1 \]  

(24)

The new layouts with “non-cross” constraint are presented in Figures 6 and 7. Now numerical results are highlighted in Tables 7, 8 and 9.

### 3.2.2. Neglecting reliability aspect in objective function

As already mentioned, the novelty in this study is the reliability assessment of the wind farm. Moreover, the previous studies have focused on minimizing of cable installation cost while neglecting the reliability aspect, i.e. the cost of lost energy. To highlight this paper’s contribution, the simulations are run with modified objective function, i.e. by minimizing cable installation cost only. Cost of lost energy and total cost are assessed simultaneously. The obtained results are presented in Tables 10, 11 and 12. Next to every numerical value is a percentage indicator that shows if the obtained value is higher or lower than the value acquired by minimizing both cable installation cost and cost of lost energy.

The results show that cable installation cost is on average 9.02% lower compared to the case when reliability aspect is considered as well. Moreover, the total cost is on average higher by 4.66% in the case with reliability aspect, i.e. the cost of lost energy. To highlight this paper’s contribution, the simulations are run with modified objective function, i.e. by minimizing cable installation cost only. Cost of lost energy and total cost are assessed simultaneously. The obtained results are presented in Tables 10, 11 and 12. Next to every numerical value is a percentage indicator that shows if the obtained value is higher or lower than the value acquired by minimizing both cable installation cost and cost of lost energy.

The results show that cable installation cost is on average 9.02% lower compared to the case when reliability aspect is considered as well. Moreover, the total cost is on average higher by 4.66% in the case with modified objective function. This example helps in emphasizing the importance of reliability assessment when planning the onshore wind farm.
4. Conclusion

This paper aims to find the optimal cable layout of an onshore wind farm using a MILP approach. The MILP algorithm takes into account system reliability, power transfer capacities and power quality issue. The novelty in this optimization algorithm is to simultaneously minimize cable installation cost and cost of lost energy production, and dynamically update failure rate of every node, while deciding on the network outline.

Additionally, the algorithm supports selection of the optimum cable among different cable options, with different prices and capacities. By monitoring and controlling the voltage increase at POC, power quality issue is considered as well.

To analyze the effectiveness of the algorithm, four different layouts (with different POCs) are considered. Each layout is evaluated for three scenarios, depending on the type(s) of cable(s) involved in the simulation. It has been shown that the layout with POC4 in every scenario gives the best (lowest) values for total cost. By introducing more cable options, total costs are decreasing for every layout. It has also been shown that cables with bigger capacity contribute to lower values of voltage increase at POC. Additionally, these cables have the ability to support supply from more turbines, creating longer feeders. However, these longer feeders negatively affect system reliability and therefore cost of lost energy production.

The wind farm electrical system must meet local electrical safety requirements, should achieve an optimum balance between costs and reliability and must ensure that the wind farm satisfies the technical requirements of the electricity network operator [2]. The designed approach successfully implements these requirements and assists planners and experts in the onshore wind farm design.

CRediT authorship contribution statement

Sanja Duvnjak Zarković: Conceptualization, Methodology, Software, Investigation, Visualization. Ebrahim Shayanesteh: Conceptualization, Software, Supervision. Patrik Hilber: Conceptualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors thank SweGRIDS, the Swedish Centre for Smart Grids and Energy Storage, for funding the project. Moreover, the authors thank Daniel Fahlgren from Ellevio AB and Carl Johan Wallnerström from Energinomarknadsinspektionen for providing valuable data and practical information for this project.

Appendix A

| Table 13 | Distances between nodes |
|----------|-------------------------|
|          |  POCT  | POCT  | POCT  | WT1  | WT2  | WT3  | WT4  | WT5  | WT6  | WT7  | WT8  | WT9  | WT10 | WT11 | WT12 | WT13 |
|          |    m   | POCT  | POCT  | POCT  | WT1  | WT2  | WT3  | WT4  | WT5  | WT6  | WT7  | WT8  | WT9  | WT10 | WT11 | WT12 | WT13 |
| POCT1    | 0     | -     | -     | -     | 209.1 | 439.1 | 1002.0 | 701.6 | 1290.0 | 912.5 | 963.2 | 1180.0 | 1360.0 | 1490.0 | 1850.0 | 1980.0 | 2360.0 |
| POCT2    | -     | 688.0 | 245.0 | 1370.0 | 0     | 537.8 | 1180.0 | 525.1 | 1120.0 | 798.3 | 964.7 | 1260.0 | 1290.0 | 1470.0 | 1780.0 | 1940.0 | 2270.0 |
| POCT3    | -     | -     | 336.0 | 1390.0 | 537.8 | 0     | 634.1 | 786.9 | 1260.0 | 775.1 | 629.4 | 753.8 | 1120.0 | 1610.0 | 1640.0 | 2090.0 |
| POCT4    | -     | -     | -     | 245.0 | 336.0 | 1470.0 | 614.0 | 1190.0 | 1000.0 | 1200.0 | 1550.0 | 1500.0 | 1720.0 | 1960.0 | 2180.0 | 2450.0 |
| POCT5    | -     | -     | -     | -     | 0     | 1370.0 | 1390.0 | 1750.0 | 856.0 | 323.0 | 611.0 | 961.0 | 1400.0 | 539.0 | 1040.0 | 633.0 | 1080.0 |
| POCT6    | 209.1 | 688.0 | 245.0 | 1370.0 | 0     | 537.8 | 1180.0 | 525.1 | 1120.0 | 798.3 | 964.7 | 1260.0 | 1290.0 | 1470.0 | 1780.0 | 1940.0 | 2270.0 |
| POCT7    | 439.1 | 378.0 | 336.0 | 1390.0 | 537.8 | 0     | 634.1 | 786.9 | 1260.0 | 775.1 | 629.4 | 753.8 | 1120.0 | 1610.0 | 1640.0 | 2090.0 |
| POCT8    | 1002.0 | 630.0 | 1470.0 | 1750.0 | 1180.0 | 634.1 | 0     | 1370.0 | 1700.0 | 1190.0 | 776.8 | 481.0 | 1310.0 | 1010.0 | 1710.0 | 1560.0 | 2130.0 |
| POCT9    | 701.6 | 1100.0 | 614.0 | 856.9 | 525.1 | 786.9 | 1370.0 | 0     | 613.6 | 425.6 | 834.0 | 1236.0 | 934.1 | 1260.0 | 1360.0 | 1620.0 | 1870.0 |
| POCT10   | 1290.0 | 1610.0 | 1190.0 | 323.0 | 1120.0 | 1260.0 | 1700.0 | 613.6 | 0    | 512.3 | 970.5 | 1440.0 | 709.2 | 1200.0 | 962.2 | 1350.0 | 1420.0 |
| POCT11   | 912.5 | 1170.0 | 1000.0 | 611.0 | 798.3 | 775.1 | 1190.0 | 425.6 | 512.3 | 0    | 485.7 | 949.4 | 507.2 | 838.6 | 956.3 | 1260.0 | 1400.0 |
| POCT12   | 963.2 | 950.0 | 1240.0 | 961.0 | 964.7 | 629.4 | 776.8 | 834.0 | 970.5 | 485.7 | 0    | 479.3 | 531.5 | 507.0 | 994.1 | 1010.0 | 1470.0 |
| POCT13   | 1180.0 | 972.0 | 1550.0 | 1400.0 | 1260.0 | 753.8 | 481.0 | 1260.0 | 1440.0 | 949.4 | 479.3 | 0    | 906.5 | 551.8 | 1260.0 | 1090.0 | 1660.0 |
| POCT14   | 1360.0 | 1470.0 | 1500.0 | 539.0 | 1290.0 | 1120.0 | 1310.0 | 934.1 | 709.2 | 507.2 | 531.5 | 906.5 | 0    | 503.5 | 510.2 | 719.1 | 997.8 |
| POCT15   | 1490.0 | 1400.0 | 1720.0 | 1040.0 | 1470.0 | 1110.0 | 1010.0 | 1260.0 | 1200.0 | 838.6 | 507.0 | 551.8 | 503.5 | 0    | 751.9 | 560.4 | 1130.0 |
| POCT16   | 1850.0 | 1950.0 | 1960.0 | 633.0 | 1780.0 | 1610.0 | 1710.0 | 1360.0 | 962.2 | 956.3 | 994.1 | 1260.0 | 510.2 | 751.9 | 0    | 481.6 | 502.5 |
| POCT17   | 1980.0 | 1960.0 | 2180.0 | 1080.0 | 1940.0 | 1640.0 | 1620.0 | 1350.0 | 1200.0 | 1010.0 | 909.0 | 701.9 | 560.4 | 481.6 | 0    | 630.4 |
| POCT18   | 2360.0 | 2430.0 | 2450.0 | 1060.0 | 2270.0 | 2090.0 | 2130.0 | 1870.0 | 1420.0 | 1480.0 | 1470.0 | 1660.0 | 997.8 | 1130.0 | 502.5 | 630.4 | 0    |
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