

Conception of Low Voltage Network Loss Reduction Based on Integrated Information

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Abstract: Significance of business and technical information system integration in distribution utility using geographical information system (GIS) is presented in this paper. Motives for GIS base creation are depicted as basis for network operation improvement and loss reduction. Improvements of software for network planning and analysis that include GIS elements are described, specially those related to future loss reduction application. Conception of loss reduction based of collected GIS and energy data in Serbian distribution networks is presented. Presentation is gradual: from the most detailed data set to the least detailed but necessary data set collected in distribution utilities.

Keywords: Low voltage network, loss reduction, GIS, BIS.

1 Introduction

Improvement of computers' power and applied software enables processing more and more data. Quality data processing, from the other side, demands integration of information from different sources: business, technical, geographical, and all sorts of measurements. Lately, geographical information systems became efficient tool for business and technical data integration, above all because of its improved precision, possibility to visualize data and make them familiar to users, and the fact that systems integrated in such a way enable many different ways of data usage.

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Significance of data systematization and information systems integration by GIS is presented in separate section of this paper. In order not to be only theoretical consideration, practical way of GIS foundation is presented through improvement of existing software for distribution network analysis and planning. Special significance in operation of Serbian distribution network has high losses value and a way to reduce it. Algorithm based on systemized low voltage network and consumption data for losses reduction is also presented in this paper. Special attention is paid to a manner of algorithm adjustments and application to GIS foundation presented in this paper.

2 Significance of Data Systematization Using GIS

Geographical information systems (GIS) include data related to geographical location of certain elements of technical or business information system (TIS or BIS). Due to quality geo-referenced digitalized maps at disposal, it is possible to identify location of TIS or BIS elements and to form GIS base. Direct link among GIS, TIS and BIS will be established with unique identifier of located element from TIS or BIS (code, ID number, etc). The relation between GIS elements from different sources also establishes relation between TIS and BIS elements. The significance of linking is considered more detailed in [1].

TIS and BIS integration was the base for distribution network operation analyses and development planning in Serbia during the last decade of XX century, and at the beginning of XXI century. Integration quality and constant update of integrated information systems were recognized as problems during realization of several long-term network development studies, as well as during operational data use in both information systems. GIS involvement was motivated by ambition to improve integration quality and to upraise level of available data usage value.

BIS is base for successful distribution utility management. It contains information about electrical energy supply and sale and other utility business activities information. Due to money character of these information and bills that are subjected to control of two interested sides and tax authorities, precision of these data is very high. Time variability of these data is base for utility past operation, and their relation to TIS data is base for consumption size and disposition history, and for previous network operation analyses.

TIS is base for distribution network control and its optimal development. It contains all network elements data and electrical measurement data for different location in network. Network data are relatively constant comparing to other data sets in TIS and BIS. Network data input into TIS is regulated by utility internal

procedures and it is under permanent internal control, but, basically, it depends on conscientious work of responsible staff. Intensive TIS usage for network control and development planning produces high level of data precision. As for measurement data, although modern SCADA systems enable huge data sets collection, not all relevant spots are included in remote data collection systems. Some imprecise equipment produces measurement data, which can be applied only after additional information. Historical measurement data analyses, which are of great importance for future conclusions, are possible after inclusion of data that are not originally part of TIS.

GIS implementation is not completely new in Serbian distribution utilities [2]. However, research results, development and application of GIS presented in this paper are partly motivated by urgent usage of GIS collected and systematized data, for operational activities, network analyses and planning, and, specially, for low voltage loss reduction. Developed application, presented in the second part of paper, was adapted for these purposes.

Supplying MV/LV substation and supplying LV feeder assignment to every consumer in BIS is base for BIS and TIS integration. Identification of each consumer on geo-referenced digitalized map in GIS enables GIS and BIS integration. Identification of each network element on geo-referenced digitalized map in GIS and overall network topology inside GIS enables GIS and TIS integration. High precision during integration is very significant property of integration process. Some data are not at disposal, or at least they are not systemized adequately, so GIS application as integration tool is a chance for adequate data systematization. Even if low voltage network disposition is available, consumers and their supplying MV/LV substation identification on digitalized map could be good bases for efficient network reconfiguration or even for LV network reinforcement.

3 GIS implementation for network control improvement and loss reduction

Distribution network analyses imply access to: 1) geo-referenced network data, 2) consumption data by supplying network elements, 3) measured loads by network elements.

The first data group is part of GIS, but usually, it is not at disposal as a part of GIS, but as hard copy, part of TIS, or part of distribution management system (DMS) software. Software for network analysis usually serves as a tool for network planning, and, as such, it demands detailed geographic data insight, and this is basic condition for GIS creation. Actual Serbian practice is that software for network

analysis and planning resembles GIS considering manipulation with this data set. The second data set implies TIS and BIS integration: link between consumption data and supplying network element for each consumer. Before GIS implementation, integration is realized by analyzing list of consumers. Utility's trade and maintenance staff are included in this process simultaneously, which is hard to organize and this process has reduced precision without visual insight.

GIS as integration tool assume TIS functionality, which is significant from accuracy and systematization points of view. Consumer identification on geo-referenced digitalized map, followed by supplying network element identification, enable separate work of trade and maintenance staff during integration.

Visualization aspect during consumer identification improves precision of whole work and update process. Availability of data for other applications (available list of supplied consumers from MV/LV substation, identification of out-of-order network elements during outage and fault location, etc.) improves data up-to-date-ness.

One of the most significant motives for creation of GIS application and its usage for TIS and BIS integration is possibility to use data to reduce LV network losses. Utility can use collected data for LV network reconfiguration and MV/LV substation capacity optimization. Utility can also use GIS data for visual detection of objects without connection to network, which can be potential unauthorized consumers.

4 Description of Software Improvements for GIS Elements Implementation with Emphasis to Loss Reduction

From the above reasons, GIS oriented application is implemented into existing software for network analyses and planning. It enables positioning of consumers on digitalized geo-referenced map and their connection to supplying MV/LV substation for each consumer. Software has previously enabled network data input on the same maps, which made possible TIS and BIS integration through retrieving energy consumption data and their link to supplying network elements.

Input data maps are digitalized raster maps in bitmap format. Geo-referencing in software is made using known coordinates of two points (usually bottom left and top right points), and this is usually information available for maps at disposal.

Network and consumers data input are performed through location selection on visible part of map, and then through definition of properties for specified element. Several forms are presented below in order to illustrate input data. As it is presented on fig. 4 it is possible to assign supplying MV/LV substation and supplying LV

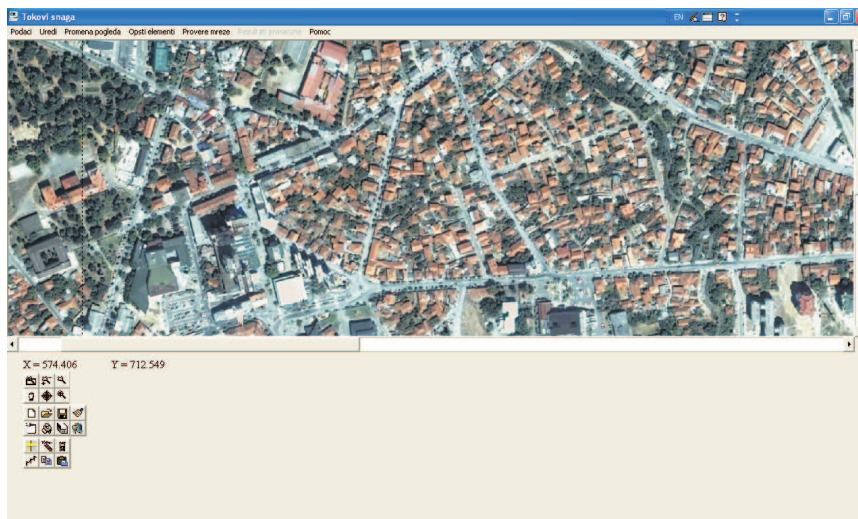


Fig. 1. Example (city of Vranje) of geo-referenced digitalized map within software with coordinates presented on screen.

feeder to each consumer (i.e. to each consumer’s connection point). Additional consumer data (name, surname, address) presented on fig. 5 are important for searching purposes, while consumed energy date is significant in loss reduction analyses.

Podaci o cvoru							
Naziv cvora	Nemanjina 630 kVA						
Sifra cvora	1032						
Broj oblasti cvora	1						
Generisana snaga							
Aktivna (MW)	0.000						
Reaktivna (MVar)	0.000						
Opterećenje							
Aktivno (MW)	0.733						
Reaktivno (MVar)	0.263						
Koordinate cvora							
X koordinata	574.698						
Y koordinata	712.664						
Ostali podaci							
Qkomp (MVar)	0.060						
Broj potrosaga	0						
Podaci o naponu cvora (kV)							
Nominalni napon	10	Bazni napon	10.00	Minimalni napon	8.00	Maksimalni napon	10.70

Fig. 2. Network node (for example MV/LV substation) input form.

Because of large number of consumers, it was necessary to develop efficient and user friendly interface for data input and processing (fig. 6 - fig. 8).

Insight into consumers disposition supplied from selected MV/LV substation,

Fig. 3. Line data input form.

or supplying substation for selected consumer is possible through image adjustment and illustration color selection (fig. 9).

Developed application enables quick data manipulation and performing simple queries important for network analysis and planning.

5 Algorithm for Low Voltage Network Loss Reduction Considering Availability of Full Data Set and Lack of Some Data

Algorithm for low voltage network reconfiguration is based on algorithm presented in [3] for medium voltage network reconfiguration. Application of this algorithm was successfully validated during last ten years, as illustrated in [4, 5]. Algorithm modifications were performed keeping in mind specifics of low voltage network comparing to medium voltage network.

Considering the fact that configuration of low voltage network is relatively permanent, algorithm speed is not essential. Thermal limits of network elements should be included as constraints into algorithm.

The first step in the algorithm is determining consumers' active and reactive

The screenshot shows a software window titled "Podaci o prikljucku" (Data about connection point). The window is divided into several sections:

- Sifra prikljucka:** 012260
- Naselje:** (empty field)
- Koordinate prikljucka:**
 - X koordinata: 574.513
 - Y koordinata: 712.593
- Potrosaci na prikljucku:**
 - Potrosacki broj: (empty field)
 - Tabela: (button)
 - ^: (button)
 - Broj potrosaca na prikljucku: 4
 - 7710011389835 (selected)
 - 7710011554542
 - 7710011554623
 - 7710017035083
- Napojna TS:**
 - Naziv (selected) • Sifra
 - Nazivi napojnih TS: Karadjordjeva 630 kVA (dropdown)
 - Napojna TS: 1039 (text field)
 - Bez napojne TS (button)
 - Broj NN izvoda: 0 (text field)
- STOSIC PREDRAG:**
 - Detalji o potrosacu (button)

At the bottom of the window, there are two buttons: "Upisi" (Save) and "Otkazi upis" (Cancel save).

Fig. 4. Consumer connection point input data.

powers as a basis for optimal network reconfiguration. Active energy consumption is available for all low voltage consumers, but for some of them, reactive energy consumption and maximal active power in specified period are available, too. If performed measurement allow, consumers should be categorized into several categories according their daily consumption diagram for winter day with maximal consumption. Keeping in mind that only monthly (and not daily) consumption data are available, and that daily consumption diagrams are similar during one month for selected consumer's category, as a basis for transformation of daily consumption diagram from relative to absolute units, maximum of daily diagram is selected to feet area under load curve with average consumption of that consumer, during that month (i.e. month with maximal daily consumption). In this way, all calculation in algorithm are related to average load in month with maximal load. To simplify procedure, and enable further data processing, attained daily diagrams are linearized hourly (or at every fifteen minutes), or additionally simplified and made constant hourly.

After creating previously described simplified daily load diagrams for all consumers sum of all of them is performed in order to find maximal load and participation of each consumer in maximal load. If no daily load diagrams are available,

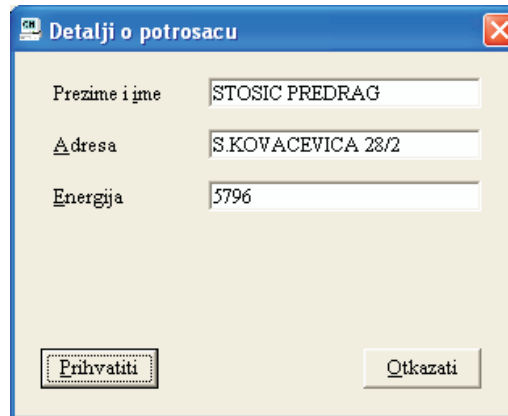


Fig. 5. Additional consumer data (Name and surname, address and consumed energy).

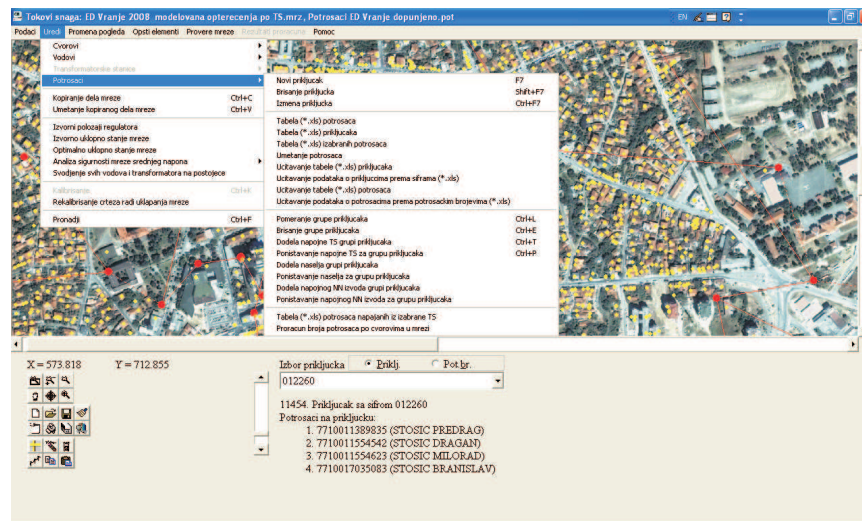


Fig. 6. Possible consumer and their connection points operations (importing and exporting data through Excel, graphical assignment of supplying network element, or consumer's settlement, etc.).

consumer's load is calculated from annual energy consumption and equivalent duration of maximal load (2000 hours) for low voltage feeders, which is adopted on empirical basis.

Minimization of losses is performed considering low voltage network, so, different losses in medium and high voltage network are not considered for different low voltage network states. This assumption is reasonable considering small loss changes in medium, and especially high voltage network. Namely, changing of

Potrošački broj	Napojna TS	Napojni NN izvodi	x koordinata potrošača (km)	y koordinata potrošača (km)	Sifra potrošača	Prezime i ime potrošača	Naselje	Adresa potrošača	Energija potrošača (kWh)
2	7710011322661	1039	0	574.3754	712.6146	012410	SMILJKOVIC TOMISLAV	KARADJORDJEVA 16	10543
3	7710011322380	1039	0	574.3513	712.2988	012409	JOVANOVIC MIRODRAO	KARADJORDJEVA 14	0
4	7710011322547	1039	0	574.3086	712.6245	012403	MILOSAVLJEVIC VLADIMIR	KARADJORDJEVA 18	4465
5	7710011322741	1039	0	574.3714	712.61	012403	ZLATKOVIC MILIVOJE	KARADJORDJEVA 18	8145
6	7710011322822	1039	0	574.3714	712.61	012402	ZLATKOVIC DRAGAN	KARADJORDJEVA 18	6819
7	7710011322903	1039	0	574.3714	712.61	012402	ZLATKOVIC DRAGAN	KARADJORDJEVA 18	130
8	7710010909099	1039	0	574.3737	712.6294	012372	ZDRAVKOVIC MIRODRAO	KARADJORDJEVA 21	10216
9	7710011378124	1039	0	574.3737	712.6294	012372	ZDRAVKOVIC STOJAN -441-	KARADJORDJEVA 21	2134
10	7710011378205	1039	0	574.3737	712.6294	012372	MILENTIJE KRNJATOVIC	KARADJORDJEVA 21	1977
11	7710011378396	1039	0	574.3737	712.6294	012372	ZDRAVKOVIC STOJAN	KARADJORDJEVA 19	99
12	7710011377900	1039	0	574.3603	712.6191	012371	DUKIC DRAGAN	KARADJORDJEVA 17	0
13	7710010375232	1039	0	574.332	712.619	012370	SFASIC PETAR	KARADJORDJEVA 15	1484
14	7710010089234	1039	0	574.3622	712.5413	012327	ALEKSIC BRANKICA	V. ANTICA 19 VRANJE	11304
15	7710010089153	1039	0	574.3719	712.5381	012326	STOILKOVIC VLADIMIR	V. ANTICA 19 VRANJE	6922
16	7710010322487	1039	0	574.3719	712.5381	012326	STOILKOVIC VLADIMIR	V. ANTICA 19	8991
17	7710010089915	1039	0	574.3817	712.5499	012325	STOILKOVIC BOZIDAR	V. ANTICA 21 VRANJE	2
18	7710010233464	1039	0	574.3817	712.5499	012325	STOILKOVIC BOZIDAR	V. ANTICA 21	12865
19	7710010089404	1039	0	574.3813	712.5638	012324	ESTIC SERAFIM	V. ANTICA 23 VRANJE	0
20	7710010091051	1039	0	574.4129	712.5628	012323	JEVIC SVOJIN	V. ANTICA 242 VRANJE	8046
21	7710010091131	1039	0	574.4012	712.5729	012322	ALEKSOV GORAN	V. ANTICA 241 VRANJE	11146
22	7710010091212	1039	0	574.4012	712.5729	012322	CVETKOVIC MIRODRAO	V. ANTICA 241 VRANJE	7932

Fig. 7. Exported consumer's data (ID number, supplying substation and feeder, coordinates, nam and surname, settlement, address, energy).

Podaci o potrosacima koji se ucitavaju

- X koordinata potrosaca (km)
- Y koordinata potrosaca (km)
- Sifra napojne TS
- Broj NN izvoda
- Prezime i ime
- Naselje
- Adresa
- Energija

Prihvatiti Otkazati

Fig. 8. Possible consumer's data to export to Excel file (coordinates, supplying substation and feeder, name and surname, settlement, address, or energy).

supplying MV/LV substation for some consumers usually changes load disposition along the same MV feeder. Effects to overall MV losses are negligible.

Secondary sides of MV/LV substations are defined as supplying points for low voltage network and losses are considered beginning with these points. To speed up algorithm two preliminary steps are performed:

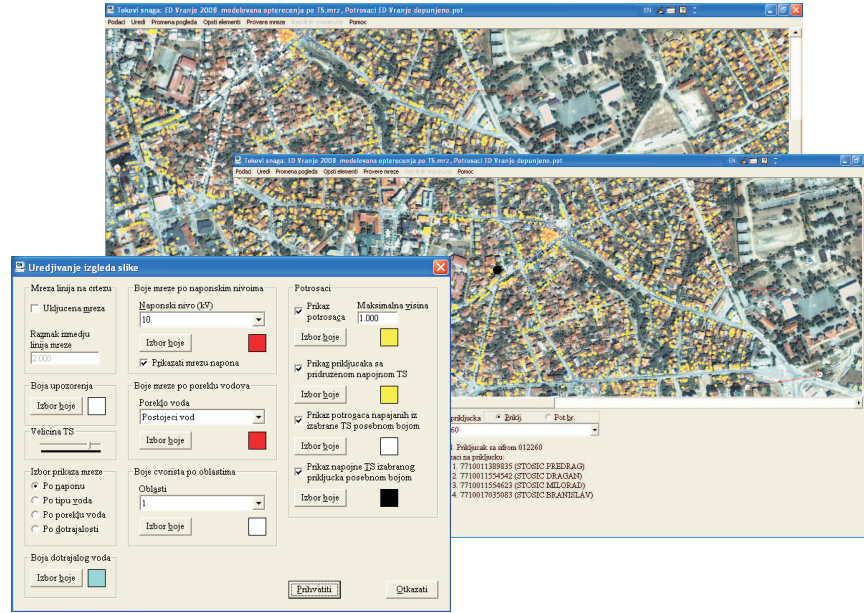


Fig. 9. Supplied consumers from selected MV/LV substation (white), supplying substation (black) for selected consumer and parameters of application image adjustment.

1. Number of nodes in network is reduced by eliminating nodes with no load, and creating equivalent lines instead of lines connected to these nodes.
2. Radially supplied nodes are reduced to their supplying nodes with possibility of two way fed from MV/LV substation. After reduction, total load of eliminated nodes is added to their supplying node. To be precise, beside load, losses should be added to, but considering that loss percentage is rarely above 5%, obtained error has small influence to optimal configuration.

With previous steps number of nodes in reconfiguration process is significantly reduced (no radial, nor load nodes), with algorithm significantly accelerated.

Optimization process is performed through iteration procedure where supplying direction is defined for one by one node. In one iteration, one node is determined with supplying line switched on. Therefore, supplying direction is established for this node. Of course, supplying line must come from node for which supplying direction was previously defined. Iteration procedure is performed until all nodes get their supplying direction.

To create criteria for node selection with defined supplying direction, transmission value (VP) concept is defined:

$$VP_{ij} = VP_{jk} - Penal \cdot R_{jk} (2P_{jk}P_{eqvy} + P_{eqvy}^2) \quad (1)$$

where j, k are nodes with already defined supplying direction, where i is node - candidate for establishing supplying direction in current iteration, where VP_{ij} is transmission value from node j to node i , where VP_{ik} is transmission value from node k to node i , with $VP_{ii} = 0$ initialized, where line $j - k$ is overload penalization factor, where R_{jk} is line $j - k$ resistance, where $P_{eqv k}$ is node k equivalent active load - with loads of reduced nodes supplied from k included, where P_{jk} is line $j - k$ equivalent active load flow with node i equivalent load not included (before establishing supplying direction for node i) - this load flow is sum of load of all nodes along the line from node j to node i except node i .

Illustration of some elements from previous formula is presented on fig. 10.

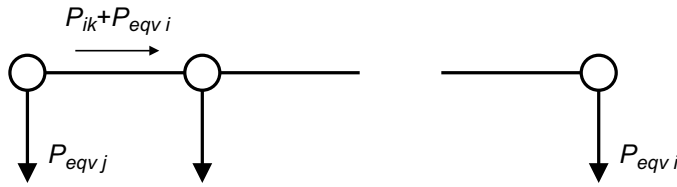


Fig. 10. Elements of formula (1) illustration.

Penalization factor increases transmission value in overloaded lines. It is calculated as:

$$Penal = a^{10 \left(\frac{P_{jk} + P_{eqvi}}{Tolerance S_{nom jk}} - 1 \right)} \quad (2)$$

where $S_{nom jk}$ is line $j - k$ nominal apparent power, where $Tolerance$ is tolerated element's overload factor, where a is penalization base.

Values $S_{nom jk}$, a , and $Tolerance$ are input values for considered algorithm. If fraction in formula (2) exponent is less than 1, function $Penal$ is fixed to 1.

Penalization factor increases transmission value in accordance with element's overload. Formula (2) shows that it depends exponentially from overload value, and this formula is heuristic.

If load of an element exceeds predefined value, this element cannot be switched on.

For all nodes with supplying direction not defined, and with adjacent nodes with supplying direction defined, minimal and next to minimal transmission value from some nodes, with supplying direction defined, are determined. Adequate supplying directions are determined, and only its part to nodes with supplying direction defined. The rests of supplying routes are already defined.

Supplying line (belonging to corresponding supplying path) for the node with the least quotient of minimal and next to minimal transmission values is switch on. Because of that, only nodes with at least one neighboring node with supplying

path defined or at least one neighboring node that is supplying point are treated in process of determining minimum and next to minimum transmission value.

Iterative procedure is repeated until all nodes have defined radial supplying paths. It happens that during iterative procedure minimum transmission value cannot be determined for any of nodes because of unallowable overload of supplying elements. In that case, tolerated overload limit is increased by predefined value. The final result of algorithm is radial network configuration with minimal losses.

Reactive power neglect does not have significant influence to optimal network reconfiguration because of reactive load flow small influence to losses. Tolerated element's overload factor serves to include reactive power influence to apparent power.

In the previous chapter GIS is initialized with no low voltage network data, but only consumers' locations and supplying MV/LV substation data. This kind of GIS basis creation was initial foundation for medium voltage network planning, but presented algorithm can be applied in such incomplete-data case with certain assumptions.

Low voltage network topology identification is based on consumers' disposition, and it is performed through connection of adjacent nodes, with constraint that each consumer can be connected only to two other, the closest (or to supplying MV/LV substation, if it is the closest). No closed loops with only consumers included are allowed during this activity. To respect expected longer line length than the shortest actual distance between nodes (consumers, or supplying MV/LV substations), as a consequence of lines following traffic infrastructure, 40% longer line length than the shortest one is adopted. The most frequent line type in network is adopted as applied type for all considered lines.

Previously defined algorithm can be applied to data adjusted in presented manner.

Presentation of algorithm application will be subject of separate paper.

6 Conclusions

Role of GIS as TIS and BIS integration tool is presented in this paper. Improved precision of data integration is emphasized and possibility of many different ways to apply integrated data are presented. These and other motives for accelerated GIS are considered in separate section of this paper.

Special attention is paid to GIS foundation creation through improvement existing software for distribution network analysis and planning. Consumers' locations, their energy, and supplying MV/LV substation are the most significant data that

can be systematized through improved software. Even with no precise information about low voltage network, whose collection and systematization demands long time and many human resources, collected data can be used for analysis of losses reduction in low voltage network.

Algorithm for low voltage network losses reduction is based on similar algorithm for medium voltage network reconfiguration. It is described in details in this paper with properties related to low voltage network and consumers singled out. A way to deal with lack of low voltage network data, which is a consequence of consumers and supplying network data collection characteristics is presented in the end. It is based on network topology identification from consumers' and supplying substations' disposition and adoption of the most often low voltage line type as the only one. Presentation of algorithm application will be subject of separate paper.

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