OBJECT MODEL OF POWER SUBSTATION FOR RELIABILITY EVALUATION

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Abstract

In this paper a new model of power system substations is proposed, based on object-oriented programming. This model includes all substations' elements separately, which is contrary to the usual approach of grouping elements by experts. A practical technique to input a single line diagram and relevant elements properties is allowed too. Minimal paths can be calculated, which are the necessary basis to make other reliability calculations.

Keywords: power substation, reliability, minimal paths, object-oriented programming.

INTRODUCTON

Reliability is one of the main properties of technical systems. Usually, failure rates and durations were used as main reliability indices of power systems. Power substation can be considered as a system of their equipment – elements. Because of the huge number of elements, some heuristic methods based on grouping elements to blocks were developed [1,], [2]. These methods require too much experts' time to compose blocks and make a list of consequences of blocks' failures – so they are not widely used.

One new element-by-element completely automated method of power substation reliability calculation, based on object programming is suggested in this paper.

MODEL DESCRIPTION

One voltage level of the power substation can be represented by ring-radial structure (Fig. 1.). Ring in the middle of the figure represent one or more bus systems. This ring can be closed (rarely) or open with or without the possibility to be closed by switching devices. Usually, in single line diagrams, linearized rings are drawn.

Branches connect substation ring to other ring-radial structure in the same or different substation. Branches can be transformers, generators, lines, etc.

Fields connect branches with bus systems. The fields consist of different devices, such as disconnectors, circuit breakers, galvanic connections, etc.

Ring-radial structure has n branches and n corresponding sectors. Each sector has three segments: *radial*, *connecting* and *bus* segments.

The *bus* segment is part of substation ring with corresponding devices. The substation field is modelled as the union of radial and connecting segments. The connecting segment is a connection between field and substation ring itself, while the radial segment represent the rest of the field and the elements such as power transformers and lines which link to other voltage levels of substation or to other substations.

In the proposed model, each segment represents the union of possible single-line diagrams (Fig. 2. and Fig. 3.). The symbols "/" and "**X**" on the figures are used for disconnectors and circuit breakers, respectively.

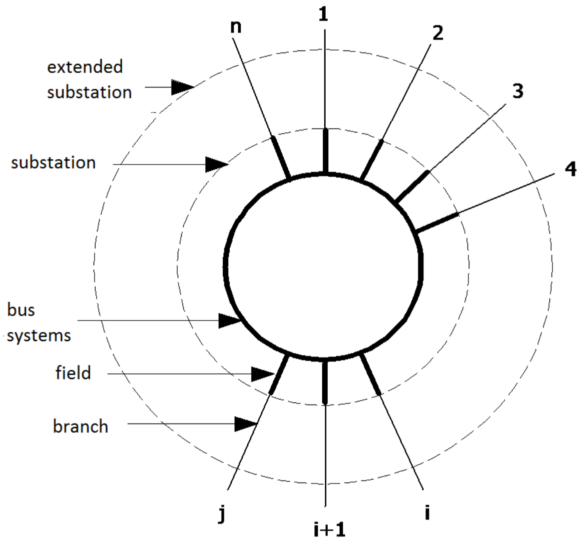

Fig. 1. Extended substation model

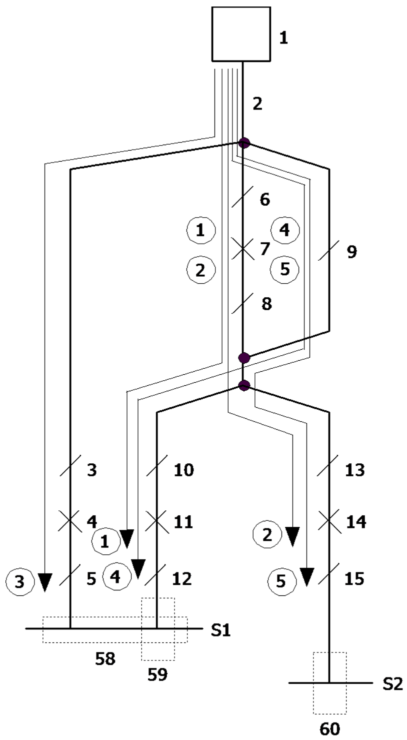

Fig. 2. Radial and connecting segment

Single line diagrams consist of elements marked with numbers. The main types of elements are:

1: galvanic connection,

2: disconnector,

3: circuit breakers,

4: line,

5: power transformer,

6: generator,

9: power source,

11: bus section with one connection (e.g. elements 59 and 60 on Fig. 2.),

12: bus section with two connection (e.g. element 58 on Fig. 2.).

The other elements, such as current and voltage transformers, which are functionally connected with above elements can be included by mentioned blocks [1].

Part of single-line diagrams of real substation is represented as subsets of elements, e.g. in radial segment:

- 1, 2 and 6 on Fig. 2. represent one bus field with disconnector only,
- 1, 2, 6, 7, 8 on Fig. 2. represent one bus field with disconnector - circuit breaker - disconnector,
- 1, 2, 6, 7, 8 and 3 on Fig. 2. represent one bus field with disconnector - circuit breaker - disconnector with bypass,
- 1, 2, 6, 7, 10, 13 and 9 on Fig. 3. represent double bus field with bypass.

On that way, all existing of substation fields can be represented.

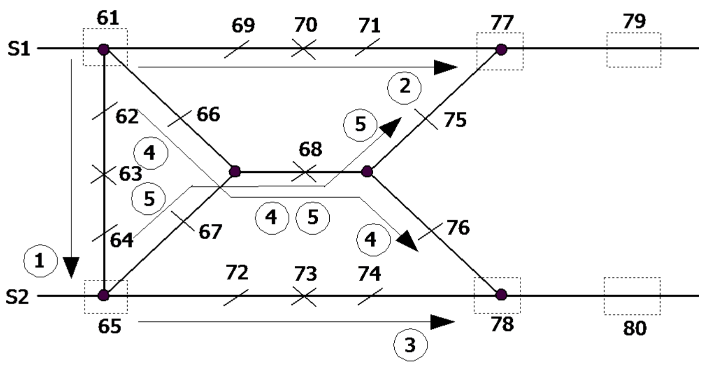

Fig. 3. Bus segment

Paths between branches and buses are marked with rounded numbers. In the last example, the paths are:

- path 1: 1, 2, 6, 7, 10 that links branch and bus system 1;
- path 2: 1, 2, 6, 7, 13 that links branch and bus system 2;
- path 4: 1, 2, 9 10 that links branch and bus system 1;
- path 5: 1, 2, 9 13 that links branch and bus system 2.

CLASS DESCRIPTION

A. CLASS EQUIPMENT

Main properties for class Equipment are:

- el_type type of element,
- f failure rate,
- fa active failure rate,
- r failure duration,
- ra switching time of active failure,
- kf correction factor for f,
- kfa correction factor for fa,
- kr correction factor for r,
- kra correction factor for ra,
- u unavailability (f * r),
- ua unavailability due to active failure (fa * ra).

Types of element are: circuit breaker, disconnector, etc. as mentioned before. Correction factors are used to set specific failure rate and duration in different segments.

B. CLASS SEGMENT

Main properties for class Segment are:

- seg_type radial, connecting and bus,
- N_bus number of bus systems,
- in_out in, out or both power flow,
- on_off on/off status of element (if applicable),
- bypass_DC filed with bypass disconnector,
- double_CB field with double circuit breaker,
- equip field equipments as object of class Equipment
- el_type type of element,
- PthElSeg paths in segment as a list of element (as marked on Fig. 1 and Fig. 2.)
- link matrix of two columns and N_Path row that describe what paths link (0 - branch, 1 - bus 1, 2 - bus 2),
- N_Path number of segment paths.

The main methods for class Segment is:

- Path (p_type, cw_ccw)
- return the list of different properties of segment path element.

First of all, Path can be expressed as a list of elements (the same as PthElSeg), but also as a list of element types (el_type) - in both cases multiplied by +1 or -1 as a mark of on-off status (-1 for open/disconnected). For galvanic connection marked as 1, mark -1 means non-existing connection, useful to represent an open ring.

Element can be listed in clockwise or counter clockwise direction in relation to substations ring.

C. CLASS SUBSTATION

Main properties for class Substation are:

- RadSeg array of radial type object of the class Segment,
- BusSeg array of bus type object of the class Segment,
- ConSeg array of connecting type object of the class Segment,
- N_Seg number of sectors (equal to number of segment of each type).

After the definition of the segment, one substation can be easily described as a collection of segments.

The main method for class Substation is:

- MinPath returns minimal paths for some substation function.

Minimal pats are the basic input for further reliability calculations [2], [4].

EXAMPLE

One single bus substation with six sectors is shown on Fig. 3. Element marks begin with sector serial number (1st digit), while the last two digits correspond to element marks on figures 1 and 2. For example, elements of sector 1 are:

- from 101 to 108 - radial segments,
- 159 - connecting segment and
- 179 - bus segment (galvanic connection only).

Minimal paths, necessary for further reliability calculation are shown on Fig. 4. There are 40 minimal paths in total, i.e. 20 pairs - first minimal path in clockwise and second one in counter clockwise direction. Eight of them end at branch 2 - these are minimal paths for reliability evaluation of supplied branch - marked with “***”. Four opened paths are underlined.

All elements on single line diagram have status on, except one - circuit breaker in sixth bus segment -670 (minus means open).

All four closed minimal paths (with all elements in status on) are underlined.

That means branch 2 is supplied from branch 1 (1st minimal path), branch 3 (14th minimal path), branch 4 (24th minimal path) and branch 6 (34th minimal path).

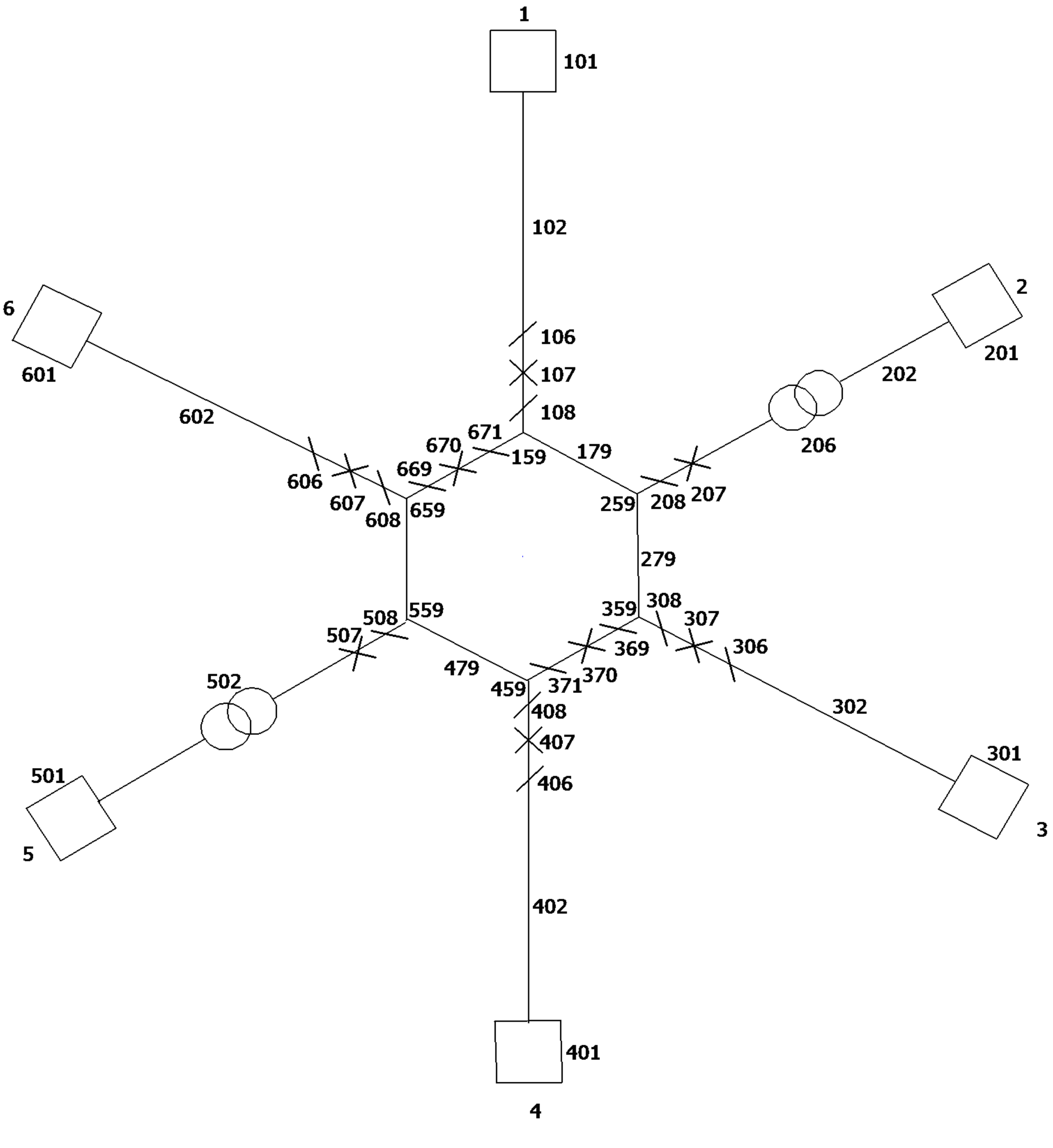

Fig. 3. *Example of a single bus substation*

```
Minimal paths (| off, - on)
No from to ...
1  1  2-***101  102  106  107  108  159  259  208  207  202  201
------------------------------------------------------------
2  1  2|***101  102  106  107  108  159  671 -670  669  659  559  459  371  370  369  359  259  208  207  202  201
3  1  3----101  102  106  107  108  159  259  359  308  307  306  302  301
4  1  3|---101  102  106  107  108  159  671 -670  669  659  559  459  371  370  369  359  308  307  306  302  301
5  1  4----101  102  106  107  108  159  259  359  369  370  371  459  408  407  406  402  401
6  1  4|---101  102  106  107  108  159  671 -670  669  659  559  459  408  407  406  402  401
7  1  5----101  102  106  107  108  159  259  359  369  370  371  459  559  508  507  502  501
8  1  5|---101  102  106  107  108  159  671 -670  669  659  559  508  507  502  501
9  1  6----101  102  106  107  108  159  259  359  369  370  371  459  559  659  608  607  606  602  601
10 1  6|---101  102  106  107  108  159  671 -670  669  659  608  607  606  602  601
11 3  1|---301  302  306  307  308  359  369  370  371  459  559  659  669 -670  671  108  107  106  102  101
12 3  1----301  302  306  307  308  359  259  159  108  107  106  102  101
13 3  2|***301  302  306  307  308  359  369  370  371  459  559  659  669 -670  671  159  208  207  202  201
14 3  2-***301  302  306  307  308  359  259  208  207  202  201
------------------------------------------------------------
15 3  4----301  302  306  307  308  359  369  370  371  459  408  407  406  402  401
16 3  4|---301  302  306  307  308  359  259  159  671 -670  669  659  559  459  408  407  406  402  401
17 3  5----301  302  306  307  308  359  369  370  371  459  559  508  507  502  501
18 3  5|---301  302  306  307  308  359  259  159  671 -670  669  659  559  508  507  502  501
19 3  6----301  302  306  307  308  359  369  370  371  459  559  659  608  607  606  602  601
20 3  6|---301  302  306  307  308  359  259  159  671 -670  669  659  608  607  606  602  601
21 4  1|---401  402  406  407  408  459  559  659  669 -670  671  108  107  106  102  101
22 4  1----401  402  406  407  408  459  371  370  369  359  259  159  108  107  106  102  101
23 4  2|***401  402  406  407  408  459  559  659  669 -670  671  159  208  207  202  201
24 4  2-***401  402  406  407  408  459  371  370  369  359  259  208  207  202  201
------------------------------------------------------------
25 4  3|---401  402  406  407  408  459  559  659  669 -670  671  159  259  308  307  306  302  301
26 4  3----401  402  406  407  408  459  371  370  369  359  308  307  306  302  301
27 4  5----401  402  406  407  408  459  559  508  507  502  501
28 4  5|---401  402  406  407  408  459  371  370  369  359  259  159  671 -670  669  659  559  508  507  502  501
29 4  6----401  402  406  407  408  459  559  659  608  607  606  602  601
30 4  6|---401  402  406  407  408  459  371  370  369  359  259  159  671 -670  669  659  608  607  606  602  601
31 6  1|---601  602  606  607  608  659  669 -670  671  108  107  106  102  101
32 6  1----601  602  606  607  608  659  559  459  371  370  369  359  259  159  108  107  106  102  101
33 6  2|***601  602  606  607  608  659  669 -670  671  159  208  207  202  201
34 6  2-***601  602  606  607  608  659  559  459  371  370  369  359  259  208  207  202  201
------------------------------------------------------------
35 6  3|---601  602  606  607  608  659  669 -670  671  159  259  308  307  306  302  301
36 6  3----601  602  606  607  608  659  559  459  371  370  369  359  308  307  306  302  301
37 6  4|---601  602  606  607  608  659  669 -670  671  159  259  359  369  370  371  408  407  406  402  401
38 6  4----601  602  606  607  608  659  559  459  408  407  406  402  401
39 6  5|---601  602  606  607  608  659  669 -670  671  159  259  359  369  370  371  459  508  507  502  501
40 6  5----601  602  606  607  608  659  559  508  507  502  501
```

Fig. 4. *All minimal paths of substation on Fig. 3.*

CONCLUSION

The proposed element-by-element model gives an efficient method of analysing the reliability of power substation including and a practical technique of inputting a single line diagram arrangement and relevant elements properties.

Minimal paths can be calculated, as a necessary basis to make other reliability calculations.

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