Rede de Distribuição Rural Trifásica a Dois Fios – Modelando o Curto-Circuito

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[[1]](#footnote-1)

***Abstract*— ESCREVAR**

***Index Terms*—KEYS IMPORTANTES**

# I. Introdução

O

método de fornecimento de eletricidade a pontos remotos e comunidades rurais distantes dos sistemas de distribuição é um desafio tecnológico e econômico. Os sistemas de distribuição monofásicos são utilizados para abastecer consumidores e pequenas cargas dispersas. O sistema monofásico com retorno por terra (SWER) é amplamente utilizado devido ao seu baixo valor de investimento e manutenção. No entanto, deve-se notar que a capacidade de carga cai drasticamente, pois a mudança ou a atualização para sistema trifásico é cara.

O [1], é a alternativa para reduzir custos de distribuição de energia em áreas remotas, com base no Energized Shields Wires Scheme (SWS) de linhas de transmissão de alta tensão. O artigo propõe quatro esquemas diferentes para fornecer cargas ao longo do traçado da linha de transmissão. O esquema trifásico utiliza dois fios blindados de uma linha de alta tensão (AT) usando resistor reator e capacitores shunts para compensar o sistema.

Em [2], demonstra como a implementação é rápida de custo baixo visto que a rede AT já existe. Visto que a aplicação em gana começava desde final dos anos 1980, esse resultado positivo, justificou a aplicação em outros países. Os países quais aplicaram essa tecnologia foram Brasil [3], Laos [2], Serra Leoa, Togo, Benin e Etiópia [1].

Em [4], os autores também descrevem as topologias de trabalho do SWER, Single Wire Isolated System, Single Wire Unisolated System e Multiwire System, entre outras. Já em [5], que o autor se baseia em quais padrões são usados como base para o sistema SWER, ambos os artigos são abordadas as capacidade de proteção do sistema.

Em [6], o autor do artigo mostra como a evolução do SWER ajudou a mobilizar a indústria rural nos Estados Unidos, em áreas onde não havia eletricidade, tornando-a mais forte no campo. E em [7], os autores apresentam o caso para atender a vila Ntenjeru qual utiliza o SWER para chegar aos consumidores. Com aproximadamente um terço do custo de instalação de um sistema convencional esse sistema se aplica a áreas quais são de baixo consumo de energia.

Em [8], os autores trabalham com a aplicação do SWER e áreas da África do Sul em áreas com menor densidade populacional e cargas em espaços rurais. Também [9], os autores trabalham com os aspectos da atualização do SWER utilizando novas tecnologias, melhorando assim a potência dos sistemas SWER existentes.

Em [10], o autor demonstra o uso de reatores shunt para compensar o sistema SWER em até 300km. Com uma melhoria de até 85% conforme as mudanças do mercado e a necessidade de mais carga.

Em [11], os autores demostram um algoritmo utilizando o modelo básico do SWER, para validar bitolas de condutores para evitar gargalos do sistema, evitando custos adicionais.

Em [12], os autores propõem a repotencialização de sistemas SWER para sistemas trifásicos a dois fios (TPTW), utilizando o solo como um elemento ativo do sistema proposto.

Em [13], os autores discutem o design de rede de distribuição rural trifásica a dois fios (TPTW), focando na compensação da reatância em série e na redução do desequilíbrio de tensão. Propõem uma metodologia para evitar a compensação da reatância e apresenta resultados de testes em vários sistemas. Os resultados mostram que, com a aplicação da metodologia e compensação RC, o desequilíbrio de tensão pode ser significativamente reduzidos.

Em [14], os autores analisam a viabilidade do sistema de energia trifásico a dois fios (TPTW) em comparação com os sistemas convencionais de três condutores. Ele destaca a eficácia do TPTW em áreas rurais em crescimento, sua capacidade de repotencializar redes existentes. Assim como a importância de uma entrega de energia econômica e sustentável. O estudo também enfatiza a consideração de vários fatores para garantir a implementação bem-sucedida do sistema TPTW.

A segunda sessão discute o sistema TPTW e seus modelos matemáticos de curto-circuito. A sessão três define os estudos de caso e resultados de comparações. A sessão quatro aplica o sistema TPTW dentro de um ramo do IEEE 34 bus e os resultados obtidos. A Quinta sessão relata as principais conclusões do trabalho.

# II. Three-Phase Two Wires

A rede proposta por [12], denominada aqui de T2F utiliza um aterramento já presente na rede MRT.O autor propõe que se utilize um transformador isolador trifásico, mas com uma das fases aterradas e duas fases aéreas. Com isso, ainda pode-se usar a estrutura existente do SWER com apenas um isolador adicional, obtendo potência trifásica. A Figura 1 ilustra a linha proposta.

Figura 1 - Rede proposta por Marchesan.

Diagrama

Descrição gerada automaticamente

Fonte: Adaptado de [13].

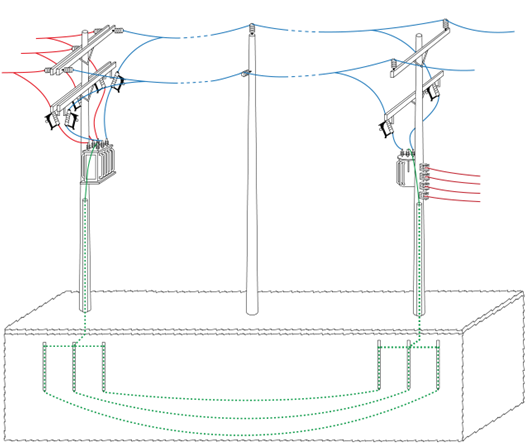
Embora haja semelhanças do T2F com o PRE, [13], enfatiza que o sistema proposto apresenta características específicas que devem ser observadas, tais como:

* Para implementar o sistema T2F é necessário utilizar um transformador de isolação que atue como intermediário entre a fonte de alimentação e a linha não convencional.
* Este transformador é alimentado por tensão trifásica simétrica em seu primário e possui uma das fases direcionada para conexão solidamente aterrada em seu secundário.
* O sistema é capaz de suprir 100% de carga trifásica através de transformadores de média tensão MT/BT convencionais, com enrolamento primário em delta e secundário em estrela aterrado.
* No entanto, devido à circulação contínua de corrente no solo, é necessário garantir que o aterramento esteja seguro para seres humanos e animais, não aqueça o solo e não interfira com as linhas telefônicas.
* Além disso, os motores trifásicos de indução de maior potência podem ser alimentados para atender às necessidades dos agricultores rurais.

Inicialmente, a instalação do transformador isolador tem como objetivo isolar o circuito de alimentação trifásico da fonte alimentadora do circuito trifásico que abastece a área rural. Isso restringe a corrente de alimentação do circuito, permitindo um melhor controle das tensões de passo e de toque, pois o monitoramento periódico tanto do aterramento do transformador isolador quanto do aterramento do consumidor é necessário.

As condições de alimentação deste transformador seguem as tensões normalmente padronizadas pelas concessionárias para a área rural e que atendem ao sistema de média tensão trifásico convencional.

Figura 2 - Modelo de rede referencia do sistema T2F.



Fonte: Adaptado, de Leonardo de Freitas Silveira.

O sistema T2F exposto na Figura 2, emprega um transformador de isolamento para conectar o sistema trifásico (vermelho) e transformar em T2F (azul) fazendo conexão com o consumidor. Os transformadores de isolamento e do consumidor utilizam a terceira fase como acoplamento por meio de um aterramento disposto no local de instalação. Para fins deste trabalho, a interface de terra é simplificada como uma única impedância.

O modelo correto do sistema, visto utilizando as capacitâncias do sistema, quais não são utilizadas para modelo de curto-circuito, o modelo de [13], mostra os modelos e sua influência na rede proposta. O modelo equivalente do sistema T2F, apresentado na Figura 3, desprezando as capacitâncias parasitas do sistema e modelando-se o modelo de rede T2F entre o transformador isolador e o transformador do consumidor.

Figura 3 - Modelo equivalente, sem capacitâncias.

Texto

Descrição gerada automaticamente

Fonte: Autor.

O desenvolvimento do equacionamento é baseado na Figura 3, assim utilizando o modelo intrínseco da Figura 4, para o desenvolvimento de equações, qual o modelo deve ser analisado utilizando as malhas para o desenvolvimento das equações. As equações de curto-circuito são necessárias analisar as malhas para apurar-se os valores corretos.

Figura 4 - Modelo de Curto-Circuito do sistema T2F.

Uma imagem contendo Texto

Descrição gerada automaticamente

Fonte: Autor.

Visto que a Figura 4, possui o modelo, onde pode-se notar que a impedância , é o resultado da associação da resistência de aterramento do transformador isolador () juntamente com a impedância de equalização do sistema (), sendo assim:

|  |  |
| --- | --- |
|  | (1) |

A Figura 4, também possui as resistências de falta, caracterizadas pelos valores , e , que representam as faltas por cada fase. Para a análise de faltas solidas, é possível calcular a corrente de falta considerando os critérios desenvolvidos na Tabela 1.

Tabela 1 - Critério de valores utilizados para faltas.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Raf (Ω) | Rbf (Ω) | Rcf (Ω) |
| Falta Trifásica ABC | 0 | 0 | 0 |
| Falta Bifásica AB | 0 | 0 | ∞ |
| Falta Bifásica AC | 0 | ∞ | 0 |
| Falta Bifásica BC | ∞ | 0 | 0 |

Fonte: Autor.

Para analisar as faltas com presença de resistências de falta, é possível fazer a troca da resistência de falta por algum valor específico qual se deseja analisar, porém para aplicar ao equacionamento, deve-se manter os valores de zero (0) e infinito (∞). Seja zero uma resistência muito pequena ou infinito uma resistência muito grande.

Assim podemos simplificar as equações, assim para obter as seguintes impedâncias:

|  |  |
| --- | --- |
|  | (2) |
|  | (3) |
|  | (4) |

Utilizando as impedâncias definidas nas equações (2), (3) e (4), podemos montar o diagrama de modelo de curto-circuito conforme a Figura 5, temos a substituição dos valores e também substituição dos valores por um único elemento.

Figura 5 - Diagrama de curto-circuito, modelo reduzido com valores substituídos.

Tela preta com letras brancas

Descrição gerada automaticamente

Fonte: Autor.

O diagrama de análise de curto-circuito demonstra três valores de impedâncias, , e , também possui um valor de mútua , qual utilizando estes componentes podemos aplicar a Lei das Tensões de Kirchhoff, assim podemos definir as seguintes equações

|  |  |
| --- | --- |
|  | (5) |
|  | (6) |

Utilizando a equação (6), podemos resolver para encontrar a corrente do ramo 2 (), assim temos uma nova equação para definir , sendo ela:

|  |  |
| --- | --- |
|  | (7) |

Com a definição de (7), podemos substituir a equação (7) dentro da equação (5), para assim definir os termos diferenciais:

|  |  |
| --- | --- |
|  | (8) |

Assim podemos fazer a distribuição conforme o terceiro termo, podemos expandir a equação (8), para:

|  |  |
| --- | --- |
|  | (9) |

Assim podemos resolver a equação (9), obtendo os valores do ramo 1 (), sendo isolados obtemos:

|  |  |
| --- | --- |
|  | (10) |

Com a obtenção da equação (10), podemos substitui-la dentro da equação (7), para obter-se a variável completa e expandida, definida por:

|  |  |
| --- | --- |
|  | (11) |

Com as equações de cada ramo definidas podemos utilizar para definir cada uma das correntes de fase separadamente, utilizando as definições das equações previamente definidas e analisando a Figura 5, podemos definir , e , conforme:

|  |  |
| --- | --- |
|  | (12) |
|  | (13) |
|  | (14) |

Conforme as equações (12), (13) e (14), podemos substituir valores de e , vamos obter as componentes completas para , e , conforme definidas por:

|  |  |
| --- | --- |
|  | (15) |
|  | (16) |
|  | (17) |

Como , é uma variável grande e dependente das outras duas, foi inserida em softwares para tentar solucionar e reduzir seu tamanho de equação, simplificando-a, porém, sem sucesso, manteve-se seu formato atual para aplicação.

## A. Abbreviations and Acronyms

Depois eu vejo

# III. MATH

Use either the Microsoft Equation Editor or the MathType plugin, which can be obtained from <https://store.wiris.com/en/products/mathtype/download>. For help with formatting and placing equations, refer to the *IEEE Editing Math Guide* at <http://journals.ieeeauthorcenter.ieee.org/wp-content/uploads/sites/7/Editing-Mathematics.pdf> and the *IEEE MathType Tutorial for Microsoft Word Users* at <http://journals.ieeeauthorcenter.ieee.org/wp-content/uploads/sites/7/IEEE-Math-Typesetting-Guide-for-MS-Word-Users.pdf>.

TABLE I

This is a Sample of a Table Title



## A. Equations

Number equations consecutively with equation numbers in parentheses flush with the right margin of the column, as in (1). First use the equation editor to create the equation. Then select the “Equation” markup style. Press the tab key and write the equation number in parentheses. To make your equations more compact, you may use the solidus ( / ), the exp function, or appropriate exponents. Use parentheses to avoid ambiguities in denominators. Punctuate equations when they are part of a sentence, as in

*Bp* + *H*2 = 40. (1)

Be sure that the symbols in your equation have been defined before the equation appears or immediately following. Italicize symbols (*T* might refer to temperature, but T is the unit tesla). When referring to an equation or formula, use simply “(1),” not “Eq. (1)” or “equation (1),” except at the beginning of a sentence: “Equation (1) is ... .”

## B. Algorithms

Algorithms should be numbered and include a short title. They are set off from the text with rules above and below the title and after the last line.

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# IV. Guidelines for Graphics Preparation and Submission

## A. Types of Graphics

The following list outlines the different types of graphics published in IEEE journals. They are categorized based on their construction, and use of color / shades of gray:

* 1. **Color/Grayscale Figures**  
     Figures that are meant to appear in color, or shades of black/gray. Such figures may include photographs,   
     illustrations, multicolor graphs, and flowcharts.
  2. **Line Art Figures**  
     Figures that are composed of only black lines and shapes. These figures should have no shades or half-tones of gray, only black and white.
  3. **Tables**  
     Data charts which are typically black and white, but sometimes include color.

## B. Multipart Figures

These are figures compiled of more than one sub-figure presented side-by-side or stacked. If a multipart figure is made up of multiple figure types (one part is line art, and another is grayscale or color), the figure should meet the stricter guidelines.

## C. File Formats for Graphics

Format and save your graphics using a suitable graphics processing program that will allow you to create the images as PostScript (PS), Encapsulated PostScript (.EPS), Tagged Image File Format (.TIFF), Portable Document Format (.PDF), JPEG, or Portable Network Graphics (.PNG). These programs can re-size them and adjust the resolution settings. If you created your source files in one of the following programs you will be able to submit the graphics without converting to a PS, EPS, TIFF, PDF, or PNG file: Microsoft Word, Microsoft PowerPoint, or Microsoft Excel. Though it is not required, it is strongly recommended that these files be saved in PDF format rather than DOC, XLS, or PPT. Doing so will protect your figures from common font and arrow stroke issues that occur when working on the files across multiple platforms. When submitting your final files, your graphics should all be submitted individually in one of these formats along with the manuscript.

## D. Sizing of Graphics

Most charts, graphs, and tables are one column wide (3.5 inches / 88 mm / 21 picas) or page wide (7.16 inches / 181 millimeters / 43 picas). The maximum depth a graphic can be is 8.5 inches (216 millimeters / 54 picas). When choosing the depth of a graphic, please allow space for a caption. Figures can be sized between column and page widths if the author chooses, however, it is recommended that figures not be sized less than column width unless when necessary.

The final printed size of author photographs is exactly   
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## E. Resolution

The proper resolution of your figures will depend on the type of figure it is as defined in the “Types of Figures” section. Author photographs, color, and grayscale figures should be at least 300dpi. Line art, including tables should be a minimum of 600dpi.

## F. Vector Art

In order to preserve the figures’ integrity across multiple computer platforms, we accept files in the following formats: .EPS/.PDF/.PS. All fonts must be embedded or text converted to outlines in order to achieve the best-quality results.

## G. Color Space

The term “color space” refers to the entire sum of colors that can be represented within the said medium. For our purposes, the three main color spaces are grayscale, RGB (red/green/blue), and CMYK (cyan/magenta/yellow/black). RGB is generally used with on-screen graphics, whereas CMYK is used for printing purposes.

All color figures should be generated in RGB or CMYK color space. Grayscale images should be submitted in grayscale color space. Line art may be provided in grayscale OR bitmap colorspace. Note that “bitmap colorspace” and “bitmap file format” are not the same thing. When bitmap color space is selected, .TIF/.TIFF/.PNG are the recommended file formats.

## H. Accepted Fonts Within Figures

When preparing your graphics, IEEE suggests that you use one of the following Open Type fonts: Times New Roman, Helvetica, Arial, Cambria, or Symbol. If you are supplying EPS, PS, or PDF files, all fonts must be embedded. Some fonts may only be native to your operating system; without the fonts embedded, parts of the graphic may be distorted or missing.

A safe option when finalizing your figures is to strip out the fonts before you save the files, creating “outline” type. This converts fonts to artwork which will appear uniformly on any screen.

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1. **Figure Axis Labels**
   1. Figure axis labels are often a source of confusion. Use words rather than symbols. As an example, write the quantity “Magnetization” or “Magnetization *M*,” not just “*M*.” Put units in parentheses. Do not label axes only with units. For example, write “Magnetization (A/m)” or “Magnetization (Am−1),” not just “A/m.” Do not label axes with a ratio of quantities and units. For example, write “Temperature (K),” not “Temperature/K.”
   2. Multipliers can be especially confusing. Write “Magnetization (kA/m)” or “Magnetization (103 A/m).” Do not write “Magnetization (A/m) × 1000” because the reader would not know whether the top axis label means 16000 A/m or 0.016 A/m. Figure labels should be legible, approximately 8- to 10-point type.
2. **Subfigure Labels in Multipart Figures and Tables**

Multipart figures should be combined and labeled before final submission. Labels should appear centered below each subfigure in 8-point Times New Roman font in the format of (a) (b) (c).

## J. Referencing a Figure or Table Within Your Article

When referencing your figures and tables within your article, use the abbreviation “Fig.” even at the beginning of a sentence. Do not abbreviate “Table.” Tables should be numbered with Roman numerals.

## K. Submitting Your Graphics

Because IEEE will do the final formatting of your article, all figures, figure captions, and tables can be placed at the end of your article. However, if you do place your figures within the article, they should be placed at the top of the page, closest to the first mention in the text. Figures should be submitted as individual files, separate from the manuscript in one of the file formats listed above. Place figure captions below the figures; place table headings above the tables. Do not include captions as part of the figures, or put them in “text boxes” linked to the figures. Also, do not place borders around the outside of your figures.

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All IEEE Transactions, Journals, and Letters allow an author to publish color figures on IEEE *Xplore* at no charge, and automatically convert them to grayscale for print versions. In most journals, figures and tables may alternatively be printed in color if an author chooses to do so. Please note that this service comes at an extra expense to the author. If you intend to have print color graphics, you will have the opportunity to indicate this in the Author Gateway and will be contacted by PubOps to confirm the charges.

V. Conclusion

A conclusion section is not required. Although a conclusion may review the main points of the article, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

# Appendix

Appendixes, if needed, appear before the acknowledgment.

# References and Footnotes

## A. References

References need not be cited in text. When they are, they appear on the line, in square brackets, inside the punctuation. Multiple references are each numbered with separate brackets. When citing a section in a book, please give the relevant page numbers. In text, refer simply to the reference number. Do not use “Ref.” or “reference” except at the beginning of a sentence: “Reference [3] shows ... .” Please do not use automatic endnotes in *Word*, rather, type the reference list at the end of the paper using the “References” style.

Reference numbers are set flush left and form a column of their own, hanging out beyond the body of the reference. The reference numbers are on the line, enclosed in square brackets. In all references, the given name of the author or editor is abbreviated to the initial only and precedes the last name. Use them all; use *et al*. only if names are not given or if there are more than 6 authors. Use commas around Jr., Sr., and III in names. Abbreviate conference titles. When citing IEEE Transactions, provide the issue number, page range, volume number, month if available, and year. When referencing a patent, provide the day and the month of issue, or application. References may not include all information; please obtain and include relevant information. Do not combine references. There must be only one reference with each number. If there is a URL included with the reference, it can be included at the end of the reference.

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Number footnotes separately in superscripts (Insert | Footnote).[[2]](#footnote-2) Place the actual footnote at the bottom of the column in which it is cited; do not put footnotes in the reference list (endnotes). Use letters for table footnotes (see Table I).

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# Acknowledgment

The preferred spelling of the word “acknowledgment” in American English is without an “e” after the “g.” Use the singular heading even if you have many acknowledgments. Avoid expressions such as “One of us (S.B.A.) would like to thank ... .” Instead, write “F. A. Author thanks ... .” In most cases, sponsor and financial support acknowledgments are placed in the unnumbered footnote on the first page, not here.

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