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Chongqing, China
July 30, 2020

To Whom It May Concern:

I am pleased to inform you that the following two patents have been granted:

Patent (1):

English title of invention: An operational reliability estimation model of improved hybrid MMC based on the thermal damage with multi-time scales

Chinese title of invention: 一种基于多时间尺度热损伤的改进混合 MMC 运行可靠性评估模型及方法
No. of patent: CN108509674A
Application date: 2018.02.06
Applicant: Chongqing University (Shazheng St., Shapingba District, Chongqing, 400044 China)
Inventors: Juan Yu, Fei Feng; **Salah Kamel**

Patent (2):

English title of invention: Mitigation of distributed generation impact on coordination of direction overcurrent relays using a novel characteristic relay curve

Chinese title of invention: 基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法

No. of patent: CN109638760B
Application date: 2018.12.29
Applicant: Chongqing University (Shazheng St., Shapingba District, Chongqing, 400044 China)
Inventors: Juan Yu; Ahmed Korashy; **Salah Kamel**; Abdel-Raheem Youssef; Francisco Jurado; Zhifang Yang; Fei Feng

Please feel free to contact me if you need any further information

Yours sincerely,

Prof. Juan YU
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重庆缙云专利代理事务所（特殊普通合伙） 王翔(02365553182)

发文日：

2018年12月30日

申请号或专利号：201811639323.X

发文序号：2018123000252600

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申请号：201811639323.X
申请日：2018年12月29日
申请人：重庆大学
发明创造名称：基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法

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首页 高级查询 IPC分类查询 LOC分类查询 事务数据查询 数据说明

公布公告查询

发明公布 发明授权 实用新型 外观设计 使用说明

类型选择

发明授权

排序方式

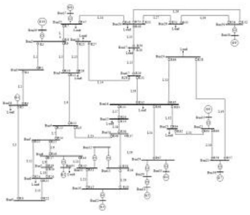
按申请日升序排序

按申请日降序排序

按公布公告日升序排序

按公布公告日降序排序

公布模式 列表模式 附图模式 每页显示3条记录



[发明授权] 基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法

授权公告号：CN109638760B 授权公告日：2020.07.21

申请号：201811639323X 申请日：2018.12.29

同一申请的已公布的文献号：CN109638760A 申请公布日：2019.04.16

专利权人：重庆大学 发明人：余娟;

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分类号：H02H1/00(2006.01)I; H02H7/28(2006.01)I 全部

摘要： 本发明公开了基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法，主要步骤为：1)确定电力系统，并获取电力系统的基本数据。2)建立方向过流继电器协调模型，使所有主继电器的工作时间之和达到最小。3)基于方向过流继电器协调模型，建立方向过流 全部

【发明专利】 【发明专利申请】 事务数据

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审查员 陈文达

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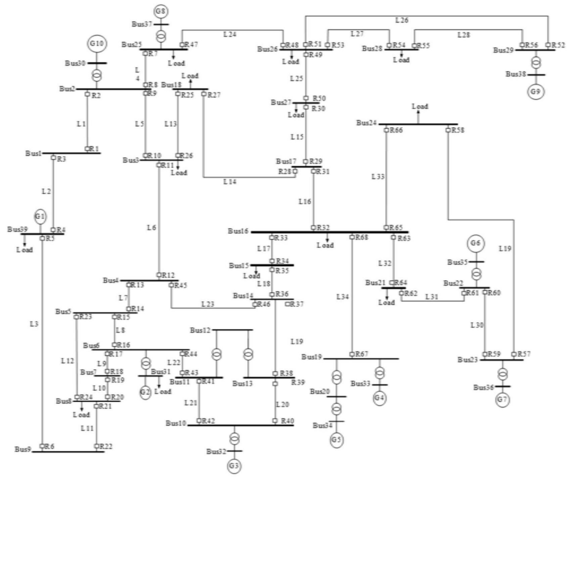
(54)发明名称

基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法

(57)摘要

本发明公开了基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法，主要步骤为：1)确定电力系统，并获取电力系统的基本数据。2)建立方向过流继电器协调模型，使所有主继电器的工作时间之和达到最小。3)基于方向过流继电器协调模型，建立方向过流继电器跳闸特性曲线。4)在检测到继电器出现过电流故障时，根据方向过流继电器跳闸特性曲线确定方向过流继电器的跳闸时间。本发明不需要断开分布式能源或重新调整继电保护整定即可解决分布式能源对继电保护协同工作的负面影响，可以显著减少所有一次继电器的总运行时间。本发明可广泛应用于分布式能源并网中方向过电流继电保护的协同工作中。



1.基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法，其特征在于，主要包括以下步骤：

1)确定电力系统，并获取电力系统的基本数据；

2)建立方向过流继电器协调模型，使所有主继电器的工作时间之和达到最小；

建立方向过流继电器协调模型的主要步骤如下：

2.1)确定继电器特性曲线的非线性数学方程，即：

$$T_n=\left(\frac{\lambda TDS_n}{(\frac{If_n}{Ip_n})^{\alpha}-1}\right);\qquad(1)$$

式中，λ和α为随继电器特性而变化的常数；n为出现过电流故障的继电器序号；TDS_n为设置的拨号时间；IP_n为第n个继电器测量得到的电流；If_n为继电器n测量的故障电流；

2.2)确定继电器参数，主要包括主继电器启动时间Tb_i、备用继电器启动时间Tp_r、TDS和第n个继电器测量得到的电流IP_n；

主继电器启动时间Tb_i与备用继电器启动时间Tp_r的关系如下所示

$Tb_i-Tp_r\geqslant CTI$；　　　　(2)

式中，CTI为协调时间间隔；

TDS如下所示：

$TDS_{min}\leqslant TDS\leqslant TDS_{max}$；　　　　(3)

式中，TDS_{min}为设置的拨号时间下限；TDS_{max}为设置的拨号时间上限；

第n个继电器测量得到的电流IP_n如下所示：

$Ip_{min}\leqslant Ip_n\leqslant Ip_{max}$；　　　　(4)

式中，Ip_{min}为电流下限；Ip_{max}为电流上限；

2.3)基于公式1至4，建立方向过流继电器DOCR的优化目标函数OF，即：

$$OF=\sum_{n}^{N}T_n;\qquad(5)$$

式中，T_n是第n个主继电器的工作时间；N为主继电器的总数目；OF为主继电器的工作时间之和；

2.4)利用MWCA方法，计算得到主继电器的工作时间之和的最小值OF_{min}；

3)基于方向过流继电器协调模型，建立方向过流继电器跳闸特性曲线；

建立方向过流继电器跳闸特性曲线的主要步骤如下：

3.1)计算PCRC指标，并建立继电器特性曲线；PCRC指标如下所示：

$$T_n=\left(\frac{\lambda TDS_n}{(\frac{If_n}{Ip_n})^{\delta}-1}\right)e^{(-1+(\frac{Vp_n}{Vs_n}))};\qquad(6)$$

式中，Vp_n为第n个继电器测量得到的相电压幅值；Vs_n为第n个继电器的规定相电压值；T_n为继电器的工作时间；δ为随继电器特性变化的常数；

3.2)设定$Vp_n=Vs_n$，基于公式6，建立第n个继电器测量得到的相电压幅值Vp_n和时间的

特性关系，并绘制方向过流继电器跳闸特性曲线；

4)在检测到继电器出现过电流故障时，根据方向过流继电器跳闸特性曲线确定方向过流继电器的跳闸时间。

2.根据权利要求1所述的基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法，其特征在于：所述电力系统主要包括方向过流继电器、主继电器、备用继电器和分布式能源DGS；

所述分布式能源DGS主要包括内燃机、燃料电池和可再生能源；

所述可再生能源主要包括风力发电、地热能发电、太阳能发电和朝夕能发电；

所述电力系统的基本数据主要包括各节点电压和电流。

基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法

技术领域

[0001]　本发明涉及继电保护领域，具体是基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法。

背景技术

[0002]　分布式发电包括风力发电、太阳能发电和生物质能发电等，有利于缓解线路阻塞、降低功率损耗以及保护环境。然而，分布式发电也会对保护系统带来不便，例如，继电器协调保护缺失，增加短路电流水平。因此，为保证电力系统的可靠安全运行，有必要仔细研究分布式发电对继电保护的影响。

[0003]　过电流保护(OCR)是一种继电保护类型，当电流幅值超过预设水平，保护开关动作。过流继电器通常和方向单元一起连接，当电流幅值超过预设水平，且电流方向和参考方向相同时，继电保护动作。如果故障位于相反方向，则不会发生任何动作。方向过流继电器(DOCR)一般应用于配电系统中，DOCR最优协调对于任何保护系统都是一个非常重要的问题。这些保护设置的正确选择对DOCR的最优协调起着重要的作用。DOCR的可靠协调意味着一次继电器应快速隔离其所在区域的故障，将系统故障限制在最小范围内，备用继电器应在一次继电保护动作后运行。

[0004]　尽管目前提出了不同的技术来减轻分布式能源渗透对DOCR协调性能的负面影响，但这些技术仍然面临许多限制。传统的优化算法，如线性规划(LP)和非线性规划(NLP)，都被用来解决该协调问题。然而，当电力系统变大时，寻找全局解的传统优化技术的失效概率也随之增加。故障检测时断开分布式电源以避免孤岛和防止其故障电流贡献是现有实践之一，这种做法存在着许多问题，如降低电力系统的可靠性、可能出现的稳定性问题等问题。

发明内容

[0005]　本发明的目的是解决现有技术中存在的问题。

[0006]　为实现本发明目的而采用的技术方案是这样的，基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法，主要包括以下步骤：

[0007]　1)确定电力系统，并获取电力系统的基本数据。

[0008]　所述电力系统主要包括方向过流继电器、主继电器、备用继电器和分布式能源DGS。

[0009]　所述分布式能源DGS主要包括内燃机、燃料电池和可再生能源。

[0010]　所述可再生能源主要包括风力发电、地热能发电、太阳能发电和朝夕能发电。

[0011]　所述电力系统的基本数据主要包括各节点电压和电流。

[0012]　2)建立方向过流继电器协调模型，使所有主继电器的工作时间之和达到最小。

[0013]　建立方向过流继电器协调模型的主要步骤如下：

[0014]　2.1)确定继电器特性曲线的非线性数学方程，即：

[0015] $$T_n=\left(\frac{\lambda TDS_n}{(\frac{If_n}{Ip_n})^{\alpha}-1}\right)。\quad(1)$$

[0016] 式中，λ和α为随继电器特性而变化的常数。n为出现过电流故障的继电器序号。TDS_n为设置的拨号时间。IP_n为第n个继电器测量得到的电流。If_n为继电器n测量的故障电流。

[0017] 2.2)确定继电器参数，主要包括主继电器启动时间Tb_i、备用继电器启动时间Tp_r、TDS和第n个继电器测量得到的电流IP_n。

[0018] 主继电器启动时间Tb_i与备用继电器启动时间Tp_r的关系如下所示

[0019] $Tb_i-Tp_r \geqslant CTI$。 (2)

[0020] 式中，CTI为协调时间间隔。

[0021] TDS如下所示：

[0022] $TDS_{min} \leqslant TDS \leqslant TDS_{max}$。 (3)

[0023] 式中，TDS_{min}为设置的拨号时间下限。TDS_{max}为设置的拨号时间上限。

[0024] 第n个继电器测量得到的电流IP_n如下所示：

[0025] $Ip_{min} \leqslant Ip_n \leqslant Ip_{max}$。 (4)

[0026] 式中，Ip_{min}为电流下限。Ip_{max}为电流上限。

[0027] 2.3)基于公式1至4，建立方向过流继电器DOCR的优化目标函数OF，即：

[0028] $$OF=\sum_{n}^{N}T_n。\quad(5)$$

[0029] 式中，T_n是第n个主继电器的工作时间。N为主继电器的总数目。OF为主继电器的工作时间之和。

[0030] 2.4)利用MWCA方法，计算得到主继电器的工作时间之和的最小值OF_{min}。

[0031] 3)基于方向过流继电器协调模型，建立方向过流继电器跳闸特性曲线。

[0032] 建立方向过流继电器跳闸特性曲线的主要步骤如下：

[0033] 3.1)计算PCRC指标，并建立继电器特性曲线；PCRC指标如下所示：

[0034] $$T_n=\left(\frac{\lambda TDS_n}{(\frac{If_n}{Ip_n})^{\delta}-1}\right)e^{(-1+(\frac{Vp_n}{Vs_n}))}。\quad(6)$$

[0035] 式中，Vp_n为第n个继电器测量得到的相电压幅值。Vs_n为第n个继电器的规定相电压值。T_n为继电器的工作时间。δ为随继电器特性变化的常数。

[0036] 3.2)设定$Vp_n=Vs_n$，基于公式6，建立第n个继电器测量得到的相电压幅值Vp_n和时间的特性关系，并绘制方向过流继电器跳闸特性曲线。

[0037] 4)在检测到继电器出现过电流故障时，根据方向过流继电器跳闸特性曲线确定方向过流继电器的跳闸时间。

[0038] 本发明的技术效果是毋庸置疑的。本发明提出了一种方向过流继电器跳闸特性曲线，以保持含分布式能源电网以及不含分布式能源电网之间的协调。本发明的目的是在协

调含分布式电源的电力系统中DOCR的保护动作。

[0039] 针对现有含分布式电源的电力系统中DOCR难以协同工作问题，本发明提出了一种DOCR新型跳闸特性曲线，来协调含分布式能源电网以及不含分布式能源电网的继电保护工作情况。

[0040] 本发明提出了新的特性曲线，不需要断开分布式能源或重新调整继电保护整定即可解决分布式能源对继电保护协同工作的负面影响，可以显著减少所有一次继电器的总运行时间。本发明可广泛应用于分布式能源并网中方向过电流继电保护的协同工作中。

附图说明

[0041] 图1为特性曲线(Vs＝0.6，TDS＝1.1)。

[0042] 图2为IEEE 39节点系统拓扑图。

具体实施方式

[0043] 下面结合实施例对本发明作进一步说明，但不应该理解为本发明上述主题范围仅限于下述实施例。在不脱离本发明上述技术思想的情况下，根据本领域普通技术知识和惯用手段，做出各种替换和变更，均应包括在本发明的保护范围内。

[0044] 实施例1：

[0045] 基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法，主要包括以下步骤：

[0046] 1)确定电力系统，并获取电力系统的基本数据。

[0047] 所述电力系统主要包括方向过流继电器、主继电器、备用继电器和分布式能源DGS。继电器是一种电控制器件。

[0048] 所述分布式能源DGS主要包括内燃机、燃料电池和可再生能源。

[0049] 所述可再生能源主要包括风力发电、地热能发电、太阳能发电和朝夕能发电。

[0050] 所述电力系统的基本数据主要包括各节点电压和电流。

[0051] 2)建立方向过流继电器协调模型，使所有主继电器的工作时间之和达到最小。解决方向过流继电器DORS协调问题的主要目的是维护电网的可靠性安全。这一目标可以通过找到最优的继电器设置以最小化所有主继电器的工作时间之和来实现，并保持继电器对之间顺序操作的有效性。

[0052] 建立方向过流继电器协调模型的主要步骤如下：

[0053] 2.1)确定继电器特性曲线的非线性数学方程，即：

[0054]
$$T_n = \left(\frac{\lambda TDS_n}{(\frac{If_n}{Ip_n})^{\alpha} - 1} \right)。 \quad (1)$$

[0055] 式中，λ和α为随继电器特性而变化的常数。n为出现过电流故障的继电器序号。TDS_n为设置的拨号时间。IP_n为第n个继电器测量得到的电流。If_n为继电器n测量的故障电流。对于标准继电器类型，λ和α分别为0.14和0.02。

[0056] 2.2)确定继电器参数，主要包括主继电器启动时间Tb_i、备用继电器启动时间Tp_r、 TDS和第n个继电器测量得到的电流IP_n。

[0057] 主继电器启动时间Tb_i与备用继电器启动时间Tp_r的关系如下所示

[0058] $Tb_i-Tp_r\geq CTI$。 (2)

[0059] 式中,CTI为协调时间间隔。

[0060] 主继电保护和后备继电器同时检测故障。备用继电器必须在一段协调时间间隔(CTI)之后启动,如果主继电器未能操作以维持选择标准并在继电器对之间创建区分裕度。CTI取决于断路器的工作时间、安全裕度和继电器类型。CTI的值从0.2到0.5s不等,这取决于继电器类型,本实施例的CTI值为0.2s。

[0061] TDS如下所示:

[0062] $TDS_{min}\leq TDS\leq TDS_{max}$。 (3)

[0063] 式中,TDS_{min}为设置的拨号时间下限。TDS_{max}为设置的拨号时间上限。

[0064] TDS_{min}和TDS_{max}是TDS的范围设置,设置为0.01s和1.1s。

[0065] 第n个继电器测量得到的电流IP_n如下所示:

[0066] $Ip_{min}\leq Ip_n\leq Ip_{max}$。 (4)

[0067] 式中,Ip_{min}为电流下限。Ip_{max}为电流上限。上限为最大负荷电流的1.5倍,下限为最小故障电流的2/3。

[0068] 2.3)基于公式1至4,建立方向过流继电器DOCR的优化目标函数OF,即:

[0069] $$OF=\sum_{n}^{N}T_n\text{。} \quad (5)$$

[0070] 式中,T_n是第n个主继电器的工作时间。N为主继电器的总数目。OF为主继电器的工作时间之和。

[0071] 2.4)利用MWCA方法(多目标水循环优化算法),计算得到主继电器的工作时间之和的最小值OF_{min}。

[0072] 3)基于方向过流继电器协调模型,建立方向过流继电器跳闸特性曲线。

[0073] 建立方向过流继电器跳闸特性曲线的主要步骤如下:

[0074] 3.1)由于分布式能源渗透,继电保护难以协调是电力系统保护面临的重要挑战之一。为了减轻分布式能源在电力系统保护中的负面影响,提出了PCRC指标。

[0075] 计算PCRC指标,并建立继电器特性曲线;PCRC指标如下所示:

[0076] $$T_n=\left(\frac{\lambda TDS_n}{(\frac{If_n}{Ip_n})^{\delta}-1}\right)e^{(-1+(\frac{Vp_n}{Vs_n}))}\text{。} \quad (6)$$

[0077] 式中,Vp_n为第n个继电器测量得到的相电压幅值。Vs_n为第n个继电器的规定相电压值。T_n为继电器的工作时间。δ为随继电器特性变化的常数。

[0078] 3.2)设定$Vp_n=Vs_n$,基于公式6,建立第n个继电器测量得到的相电压幅值Vp_n和时间的特性关系,并绘制方向过流继电器跳闸特性曲线,如图1所示。

[0079] 当故障接近继电器时,会出现较大的电压降。同样的概念被用来区分使用参数的继电器,当Vp小于Vs时,继电器的工作时间会加快,反之亦然。本实施例选取的参数Vs等于或小于后备继电器的最小Vp值,在PCRC中,继电器的工作时间不仅取决于故障期间的实测

电流，而且还取决于测量的相电压，以克服分布式能源对继电器之间协同工作的影响。所提议的特征曲线可在图1中以图形形式表示。通过设置Vp等于Vs，可以取消对传统DOCR操作时间的附加部分，而不会改变电流与时间之间的逆关系。

[0080] 4)在检测到继电器出现过电流故障时，根据方向过流继电器跳闸特性曲线确定方向过流继电器的跳闸时间。

[0081] 实施例2：

[0082] 参见图1和图2，一种验证基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法的实验，主要包括以下步骤：

[0083] 1)搭建电力系统，如图2所示，电力系统为IEEE 39节点系统，该系统由34条线路、12台变压器、10台发电机、68台DOCR、113对主、备用继电器对和136个优化变量组成。在MATLAB环境下，用2.3GHz的PC机和4GB的内存，实现了用MWCA来解决DOCR的协调问题。

[0084] 2)无分布式能源的DOCR协调

[0085] 在这一情况中，IEEE-39总线系统不安装分布式能源，并利用MWCA解决了基于传统继电特性曲线的DOCR协调问题。同样的继电保护设置用于PCSR。此外，Vs等于电压最小值。表1和表2分别列出了使用传统继电器特性曲线和PCSR的主继电器和备用继电器的工作时间样本和CTI值。

[0086] 从表1至表5可以看出，两种方法均可保持主继保和备用之间的协调，其中继电保护之间的协调裕度大于CTI。使用PCPR(13.266s)获得的所有一次继电器的总工作时间小于使用常规继电器特性(35.997s)获得的所有一次继电器的工作时间。

[0087] 表1采用传统继电器特性曲线的继电器主、后备运行时间及CTI值

[0088]

Relay pairs		$T_{Primary}$(s)	T_{backup}(s)	CTI(s)
1	4	0.5432	0.7494	0.2061
2	7	0.2089	1.0008	0.7919
2	10	0.2089	0.7946	0.5857
3	2	0.3045	0.5263	0.2217
4	6	0.3354	0.6042	0.2688
5	3	0.2255	0.4268	0.2013
6	21	0.4481	0.6508	0.2027
7	48	0.8212	1.0257	0.2044
8	1	0.5932	0.9861	0.3929
8	10	0.5932	0.7932	0.2000
10	12	0.5299	0.7311	0.2012
10	25	0.5299	0.7794	0.2495
11	9	0.5252	1.1488	0.6236
11	25	0.5252	0.7797	0.2545
12	14	0.4126	0.7376	0.3249
12	46	0.4126	0.8163	0.4036
14	16	0.5070	0.7746	0.2675
14	24	0.5070	0.9317	0.4246
15	13	0.7074	0.9100	0.2025
15	24	0.7074	0.9315	0.2240
16	18	0.6551	2.0147	1.3595
16	43	0.6551	0.9273	0.2722
17	15	0.3608	0.9149	0.5541
17	43	0.3608	0.9276	0.5667
20	22	0.1416	0.6830	0.2010
20	23	0.1416	0.3558	0.20382

[0089] 表2采用传统继电器特性曲线的继电器主、后备运行时间及CTI值

[0090]

21	**19**	**0.3333**	**0.5344**	**0.2010**
21	23	0.3333	0.5893	0.2560
22	5	0.3289	0.5295	0.2006
23	13	0.3123	0.9103	0.5980
23	16	0.3123	0.7748	0.4625
26	9	0.9471	1.1486	0.2014
27	26	1.1108	1.3283	0.2175
29	27	0.5004	1.3551	0.8547
29	32	0.5004	0.8575	0.3570
30	49	0.3787	0.8479	0.2210
31	27	0.2538	0.6963	0.6649
31	30	0.2538	0.8087	0.6733
34	36	0.2432	0.7589	0.2001
37	35	0.2554	0.8163	0.2319
37	45	0.2554	0.5815	0.2003
38	40	0.1960	0.6727	0.2277
49	47	0.3531	1.4492	0.2033
49	52	0.3531	6.6681	7.6307
49	54	0.3531	0.7775	0.2397
65	31	0.3819	0.8618	0.4798
65	34	0.3819	0.8893	0.5073
65	64	0.3819	0.8868	0.5048
65	67	0.3819	0.8996	0.5176
66	57	0.7977	1.0011	0.2033
68	31	0.1839	0.8623	0.6784
68	34	0.1839	0.8902	0.7062
68	64	0.1839	0.8872	0.7033
68	66	0.1839	0.9402	0.7563

[0091] 表3使用PCRC的继电器和CTI值的主操作时间和备份操作时间

[0092]

Relay pairs		$T_{Primary}$(s)	T_{backup}(s)	CTI(s)
1	4	0.2004	1.6295	1.4291
2	7	0.0772	0.5894	0.5121
2	10	0.0772	0.5875	0.5102
3	2	0.1121	0.8841	0.7720
4	6	0.1250	0.3884	0.2633
5	3	0.0840	0.2937	0.2097
6	21	0.1650	0.7793	0.6143
7	48	0.3023	0.9078	0.6055
8	1	0.2184	1.2123	0.9939
8	10	0.2184	0.5847	0.3662

[0093]

10	12	0.1951	0.6202	0.4250

[0094] 表4使用PCRC的继电器和CTI值的主操作时间和备份操作时间

[0095]

10	25	0.1951	0.5037	0.3086
11	9	0.1936	1.0617	0.8681
11	25	0.1936	0.5043	0.3106
12	14	0.1520	0.4791	0.3270
12	46	0.1520	0.5083	0.3562
14	16	0.1872	0.5014	0.3142
14	24	0.1872	0.7729	0.5857
15	13	0.2603	0.8624	0.6020
15	24	0.2603	0.5138	0.2535
16	18	0.2412	1.259	1.0181
16	43	0.2412	1.0400	0.798
17	15	0.1332	0.5116	0.3784
17	43	0.1332	1.0384	0.9051
20	22	0.1416	0.6830	0.5413
20	23	0.1416	0.3558	0.2142
21	19	0.1238	0.3565	0.2326
21	23	0.1238	1.1428	1.0189
22	5	0.1213	1.1580	1.0367
23	13	0.1153	2.2337	2.1183
23	16	0.1153	0.5016	0.3863
26	9	0.3488	1.0609	0.7120
27	26	0.4088	1.0218	0.6129
29	27	0.1844	0.6975	0.5130
29	32	0.1844	0.6207	0.4362
30	49	0.3787	0.8479	0.4691
31	27	0.2538	0.6963	0.4425
31	30	0.2538	0.8087	0.5549
34	36	0.2432	0.7589	0.5157
37	35	0.2554	0.81633	0.5609
37	45	0.2554	0.5815	0.3261
38	40	0.1960	0.6727	0.4766
49	47	0.3531	1.4492	1.0960
49	52	0.3531	6.6681	6.3149
49	54	0.3531	0.7775	0.4243
65	31	0.1406	0.4903	0.3497
65	34	0.1406	0.4327	0.2920
65	64	0.1406	0.4789	0.3382
65	67	0.1406	0.7544	0.6137
66	57	0.2935	0.9280	0.6345

[0096] 表5使用PCRC的继电器和CTI值的主操作时间和备份操作时间

[0097]

68	31	0.0678	0.4912	0.4234
68	34	0.0678	0.4337	0.3658
68	64	0.0678	0.4798	0.4119
68	66	0.0678	0.388901	0.3210

[0098] 3)含单一分布式发电机的测试系统

[0099] 在这种情况下，一个分布式发电机通过一个单位电抗0.01和10mVA容量的变压器连接到系统中。分布式发电机的容量为10MVA，暂态单位电抗为0.2。所有的DOCR设置都保持为原始设置。

[0100] 表6至表9分别给出了使用传统继电器特性曲线和PCRC的主继电器和备用继电器的工作时间和CTI值的样本。从表6、表7中可以看出，在常规继电器特性曲线应用于固定继电器设置时，出现了三种不协调现象。这些违反约束条件的有(R7，R48)，(R8，R10)和(R49，R54)。从表8和表9可以看出，PCRC可以保持继电器之间的协调裕度，而无需重新调整继电器设置或断开分布式发电机。

[0101] 表6采用传统继电器特性曲线的继电器主、后备运行时间及CTI值

[0102]

Relay pairs		$T_{Primary}$(s)	T_{backup}(s)	CTI(s)
1	4	0.5432	0.7493	0.2061
2	7	0.2087	0.9986	0.7899
2	10	0.2087	0.7940	0.5852
3	2	0.3045	0.5262	0.2217
4	6	0.3354	0.6042	0.2688
5	3	0.2255	0.4268	0.2013
6	21	0.4481	0.6509	0.2027
7	48	0.8196	1.0175	0.1978
8	1	0.5931	0.9861	0.3930
8	10	0.5931	0.7926	0.1995
10	12	0.5297	0.7310	0.2013
10	25	0.5297	0.7787	0.2490
11	9	0.5249	1.1481	0.6231
11	25	0.5249	0.7790	0.2540
12	14	0.4126	0.7376	0.3250
12	46	0.4126	0.8161	0.4035
14	16	0.5070	0.7746	0.2675
14	24	0.5070	0.9315	0.4244
15	13	0.7073	0.9097	0.2024
15	24	0.7073	0.9313	0.2239

[0103] 表7采用传统继电器特性曲线的继电器主、后备运行时间及CTI值

[0104]

16	**18**	**0.6551**	**2.0138**	**1.3587**
16	43	0.6551	0.9271	0.2719
17	15	0.3608	0.9148	0.5539
17	43	0.3608	0.9273	0.5665
20	22	0.3849	0.5860	0.2010
20	23	0.3849	0.5887	0.2037
21	19	0.3333	0.5344	0.2010
21	23	0.3333	0.5893	0.2559
22	5	0.3289	0.5295	0.2006
23	13	0.3122	0.9101	0.5978
23	16	0.3122	0.7748	0.4626
26	9	0.9468	1.1478	0.2009
27	26	1.1104	1.3278	0.2173
29	27	0.5003	1.3544	0.8540
29	32	0.5003	0.8575	0.3571
30	49	1.0239	1.2422	0.2182
31	27	0.6882	1.3537	0.6654
31	30	0.6882	1.3560	0.6678
34	36	0.6602	0.8603	0.2000
37	35	0.6935	0.9253	0.2318
37	45	0.6935	0.8937	0.2002
38	40	0.5317	0.7594	0.2277
49	47	0.9523	1.1622	0.2098
49	52	0.9523	5.7442	4.7919
49	54	0.9523	1.0768	0.1245
65	31	0.3818	0.8603	0.4785
65	34	0.3818	0.8890	0.5071
65	64	0.3818	0.8866	0.5048
65	67	0.3818	0.8995	0.5176
66	57	0.7977	1.0005	0.2028
68	31	0.1838	0.8608	0.6770
68	34	0.1838	0.8898	0.7060
68	64	0.1838	0.8870	0.7032
68	66	0.1838	0.9401	0.7563

[0105] 表8使用PCRC的继电器和CTI值的主操作时间和备份操作时间

[0106]

Relay pairs		$T_{Primary}(s)$	$T_{backup}(s)$	CTI(s)
1	4	0.2004	1.6296	1.4292
2	7	0.0772	0.5890	0.5117
2	10	0.0772	0.5874	0.5102
3	2	0.1121	0.8841	0.7720
4	6	0.1250	0.3884	0.2633
5	3	0.0840	0.2937	0.2097
6	21	0.1650	0.7793	0.6142
7	48	0.3017	0.9056	0.6039
8	1	0.2184	1.2123	0.9939
8	10	0.2184	0.5846	0.3662
10	12	0.1951	0.6202	0.4251
10	25	0.1951	0.5036	0.3085
11	9	0.1935	1.0619	0.8684
11	25	0.1935	0.5042	0.3106
12	14	0.1520	0.4791	0.3270
12	46	0.1520	0.5083	0.3562
14	16	0.1872	0.5014	0.3142
14	24	0.1872	0.7728	0.5855
15	13	0.2603	0.8626	0.6023
15	24	0.2603	0.5137	0.2534
16	18	0.2412	1.2588	1.0176
16	43	0.2412	1.0401	0.7989
17	15	0.1332	0.5117	0.3785
17	43	0.1332	1.0382	0.9049
20	22	0.1416	0.6830	0.5413
20	23	0.1416	0.3558	0.2141
21	19	0.1238	0.3565	0.2326
21	23	0.1238	1.1429	1.0190
22	5	0.1213	1.1580	1.0367
23	13	0.1153	2.2346	2.1192
23	16	0.1153	0.5016	0.3863
26	9	0.3487	1.0611	0.7123
27	26	0.4087	1.0218	0.6131
29	27	0.1844	0.6973	0.5128
29	32	0.1844	0.6207	0.4362
30	49	0.3769	0.8468	0.4698
31	27	0.2533	0.6961	0.4428
31	30	0.2533	0.8071	0.5538
34	36	0.2431	0.7589	0.5158

[0107] 表9使用PCRC的继电器和CTI值的主操作时间和备份操作时间

[0108]

37	**35**	**0.6935**	**0.9253**	**0.2318**
37	45	0.6935	0.8937	0.2002
38	40	0.5317	0.7594	0.2277
49	47	0.9523	1.1622	0.2098
49	52	0.9523	5.7442	4.7919
49	54	0.9523	1.0768	0.1245
65	31	0.3818	0.8603	0.4785
65	34	0.3818	0.8890	0.5071
65	64	0.3818	0.8866	0.5048
65	67	0.3818	0.8995	0.5176
66	57	0.7977	1.0005	0.2028
68	31	0.1838	0.8608	0.6770
68	34	0.1838	0.8898	0.7060
68	64	0.1838	0.8870	0.7032
68	66	0.1838	0.9401	0.7563

[0109] 4)含多个分布式发电机的测试系统

[0110] 在这种情况下,在不同的位置设置不同的分布式发电机以验证所提出的方法的有效性。通过变压器将6个分布式发电机安装到IEEE-39总线系统。在不同地点不同大小的分布式发电机详细信息见表10。表11显示了在不同位置安装分布式发电机到IEEE-39总线系统时,使用传统继电器特性曲线的主继电器和备用继电器的一些工作时间和CTI值。这个表中可以看出,在应用传统继电器特性曲线的DOCR时,存在9个节点不协调(<0.2s)。

[0111] 表12显示了使用PCRC的主中继和备份继电器的一些操作时间以及CTI值。在应用PCRC的DOCR,没有出现违反约束的情况。换句话说,可以说PCRC是足够可靠的,可以保持主中继对和备用中继对之间的协调裕度,而不需要在不存在或出现不同DGS大小的情况下更改原来的中继设置。

[0112] 表1015节点系统的最优继电保护设定

[0113]

Bus Number	DG Size
6	10
9	15
16	20
18	25
26	30
28	40

[0114]

[0115] 表11采用传统继电器特性曲线的继电器主、后备运行时间及CTI值

[0116]

Relay pairs		$T_{Primary}(s)$	$T_{backup}(s)$	CTI(s)
1	4	0.5431	0.7491	0.2060
2	7	0.2080	0.9915	0.7835
2	10	0.2080	0.7860	0.5779
3	2	0.3043	0.5258	0.2214
4	6	0.3352	0.5916	0.2563
5	3	0.2254	0.4261	0.2007
6	21	0.4385	0.6496	0.2111
7	48	0.8147	0.9948	0.1800
8	1	0.5916	0.9855	0.3939
8	10	0.5916	0.7846	0.1930
10	12	0.5248	0.7272	0.2023
10	25	0.5248	0.7644	0.2396
11	9	0.5210	1.1450	0.6231
11	25	0.5218	0.7647	0.2428
12	14	0.4109	0.7335	0.3226
12	46	0.4109	0.8111	0.4002
14	16	0.5044	0.7690	0.2646
14	24	0.5044	0.9175	0.4131
15	13	0.7042	0.9060	0.2017
15	24	0.7042	0.9173	0.2131
16	18	0.6508	1.9636	1.3127
16	43	0.6508	0.9235	0.2727
17	15	0.3586	0.9105	0.5519
17	43	0.3586	0.9238	0.5652
20	22	0.3833	0.5830	0.1997
20	23	0.3833	0.5846	0.2013
21	19	0.3320	0.5314	0.1994
21	23	0.3320	0.5851	0.2531
22	5	0.3261	0.5293	0.2032
23	13	0.3107	0.9063	0.5956
23	16	0.3107	0.7693	0.4586
26	9	0.9449	1.1447	0.1997
27	26	1.0881	1.3253	0.2372
29	27	0.4963	1.3249	0.8286
29	32	0.4963	0.8532	0.3569
30	49	1.0119	1.2230	0.2111
31	27	0.6779	1.3242	0.6463
31	30	0.6779	1.3382	0.6603
34	36	0.6574	0.8569	0.1994

[0117]

37	35	0.6906	0.9207	0.2301
37	45	0.6906	0.8876	0.1970

[0118] 表12采用传统继电器特性曲线的继电器主、后备运行时间及CTI值

[0119]

38	**40**	**0.5298**	**0.7566**	**0.2267**
49	47	0.9358	1.1589	0.2230
49	52	0.9358	6.2258	5.2899
49	54	0.9358	1.1182	0.1824
65	31	0.3789	0.8475	0.4685
65	34	0.3789	0.8833	0.5043
65	64	0.3789	0.8848	0.5058
65	67	0.3789	0.8980	0.5190
66	57	0.7963	0.9916	0.1953
68	31	0.1817	0.8480	0.6662
68	34	0.1817	0.8841	0.7023
68	64	0.1817	0.8852	0.7034
68	66	0.1817	0.9391	0.7573

[0120] 表13使用PCRC的继电器和CTI值的主操作时间和备份操作时间

[0121]

Relay pairs		$\mathbf{T_{Primary}}(s)$	$\mathbf{T_{backup}}(s)$	**CTI**(s)
1	4	0.2003	1.6305	1.4301
2	7	0.0769	0.5876	0.5106
2	10	0.0769	0.5863	0.5093
3	2	0.1120	0.8844	0.7723
4	6	0.1250	0.3857	0.2607
5	3	0.0840	0.2936	0.2095
6	21	0.1614	0.7795	0.6181
7	48	0.2999	0.9000	0.6001
8	1	0.2178	1.2126	0.9947
8	10	0.2178	0.5835	0.3657
10	12	0.1933	0.6197	0.4264
10	25	0.1933	0.5019	0.3085
11	9	0.1924	1.0628	0.8704
11	25	0.1924	0.5024	0.3100
12	14	0.1514	0.4786	0.3272
12	46	0.1514	0.5070	0.3556
14	16	0.1862	0.7658	0.5795
14	24	0.2591	0.8646	0.6054
15	13	0.2591	0.5075	0.2484
15	24	0.2396	1.2303	0.9907
16	18	0.2396	1.0416	0.8020
16	43	0.1324	0.5111	0.3787
17	15	0.1324	1.0360	0.9035
17	43	0.1862	0.7658	0.5795

[0122]

20	22	0.1410	0.6837	0.5427
20	23	0.1410	0.3546	0.2135

[0123] 表14使用PCRC的继电器和CTI值的主操作时间和备份操作时间

[0124]

21	**19**	**0.1233**	**0.3561**	**0.2327**
21	23	0.1233	1.1486	1.0252
22	5	0.1203	1.1587	1.0384
23	13	0.1147	2.2500	2.1352
23	16	0.1147	0.5011	0.3863
26	9	0.3480	1.0619	0.7138
27	26	0.4005	1.0220	0.6215
29	27	0.1829	0.6894	0.5065
29	32	0.1829	0.6214	0.4384
30	49	0.3725	0.8442	0.4716
31	27	0.2495	0.6883	0.4387
31	30	0.2495	0.8031	0.5536
34	36	0.2421	0.7593	0.5171
37	35	0.2542	0.8174	0.5631
37	45	0.2542	0.5800	0.3257
38	40	0.1953	0.6735	0.4781
49	47	0.3446	1.4502	1.1056
49	52	0.3446	4.8896	4.5450
49	54	0.3446	0.7347	0.3901
65	31	0.1395	0.4870	0.3475
65	34	0.1395	0.4305	0.2910
65	64	0.1395	0.4782	0.3387
65	67	0.1395	0.7542	0.6146
66	57	0.2929	0.9225	0.6295
68	31	0.0670	0.4879	0.4209
68	34	0.0670	0.4315	0.3644
68	64	0.0670	0.4791	0.4121
68	66	0.0670	0.3885	0.3214

[0125] 综上所述,本发明提出的基于继电器新型特性曲线缓解分布式发电对方向过流继电器协作保护影响的方法不需要断开分布式能源或重新调整继电保护整定即可解决分布式能源对继电保护协同工作的负面影响,可以显著减少所有一次继电器的总运行时间。

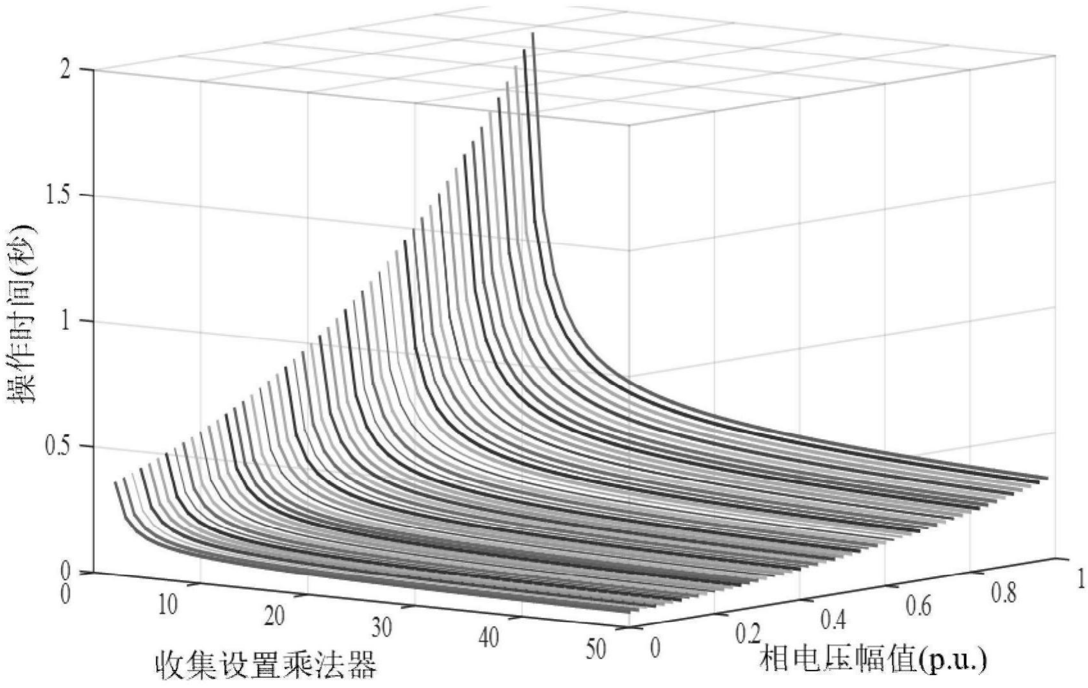
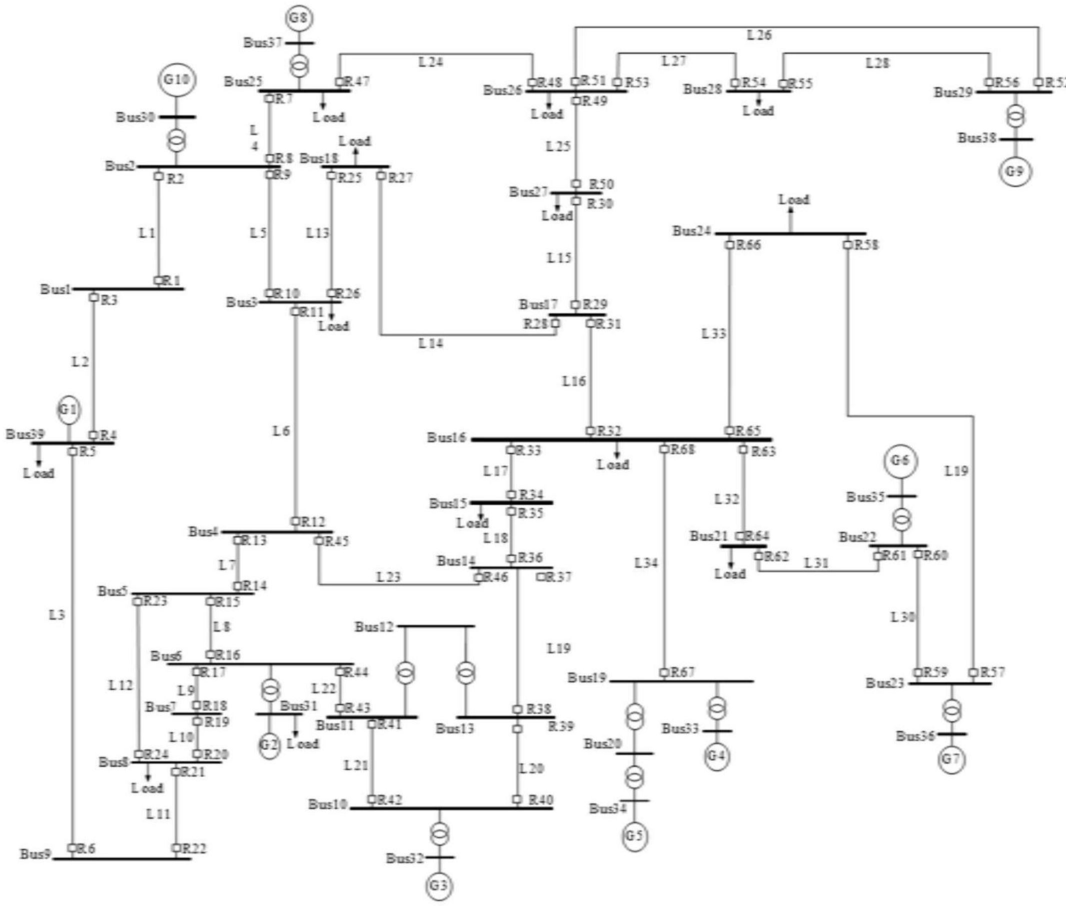


图1


G8
Bus37
Bus25
R7
R47
L24
Load
G10
Bus30
L4
R8
Bus18
R9
Bus2
R2
R25
R27
L1
L5
L13
Bus1
R1
R3
R10
R26
Bus3
R11
L2
L14
L6
G1
Bus39
R4
R5
Load
Bus4
R12
R13
R45
L7
L23
R14
Bus5
R23
R15
L3
L8
Bus6
R16
R17
R44
L12
L9
Bus31
L22
Bus7
R18
R19
R43
Bus11
R41
G2
L10
R24
R20
Bus8
R21
L11
Bus9
R6
R22
Bus12
Bus13
L21
Bus10
R42
R40
Bus32
G3
L26
L27
L28
Bus26
R48
R51
R53
R49
Bus28
R54
R55
Bus29
R56
R52
Bus38
G9
L25
Bus27
R50
R30
L15
Bus24
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R58
Bus17
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Bus14
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R46
R37
L19
L34
L32
Bus21
R64
R62
L31
Bus22
R61
R60
G6
Bus35
L30
Bus19
R67
R38
R39
L20
Bus20
Bus33
G4
Bus34
G5
Bus23
R59
R57
Bus36
G7

图2

Faculty of Engineering
Electrical Engineering Department

Aswan University

November 05, 2017

To whom it may concern,

We would like to inform you that **Mr. Ahmed Mohamed Korashy** is currently entailed to a Faculty of Engineering, Aswan University pursuing his doctoral degree.

His PhD thesis entitled: **Optimal Coordination of Directional Overcurrent Relays Using Different Matheuristic Optimization Techniques**

Mr. Ahmed is undertaking the research work under the guidance and responsibility of the following thesis supervisors:

University of Aswan

Supervisor: Salah Mohamed Kamel

University of Jaén

Supervisor: Francisco Jurado Melguizo

Department: Electrical Engineering

The above supervisors undertake to provide the fully-coordinated joint supervision of the Doctoral Thesis.

Please do not hesitate to contact me, if you have any further queries.

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METHODOLOGIES AND APPLICATION

Developed multi-objective grey wolf optimizer with fuzzy logic decision-making tool for direction overcurrent relays coordination

Ahmed Korashy[1,2] · Salah Kamel[1,3] · Loai Nasrat[1] · Francisco Jurado[2]

Published online: 6 February 2020

Abstract
This paper proposes a new methodology for solving the coordination problem of DOCRs based on multi-objective grey wolf optimizer and fuzzy logic decision-making. In addition to the conventional objective function, a new objective function which aims to minimize the discrimination time between primary and backup relays is proposed. Moreover, the conventional objective function related to minimizing the total operating time of primary and backup relays is considered. The feasibility and performance of the proposed methodology for solving the coordination problem of DOCRs are investigated using two different systems (8-bus system and IEEE-30 bus system). The proposed methodology is compared with other reported methods. The results prove the viability and effectiveness of the proposed methodology to solve the DOCR coordination problem without any miscoordination between primary and backup relays.

Keywords Direction overcurrent relays · Optimal coordination · Multi-objective grey wolf optimizer · Fuzzy logic decision-making

1 Introduction

The complexity of electric network operation is increasing as the size of the electric network is growing rapidly. Protective relays play a critical role in saving reliability and continuity of the power system. The main objectives of a protective relay are to keep healthy parts in service, clear the fault quickly by isolating only the faulty part, and maintain the reliability of the power system. DOCRs are widely applied in the distribution and sub-transmission system protection (Korashy et al. 2018). DOCRs operate when the current magnitude exceeds a reference current (pickup current) and flows in front of relay (Al-Roomi and El-Hawary 2017). If the fault is located behind the relay, then no action will take place (Costa et al. 2017). The coordination of DOCRs is considered as a nonlinear optimization problem with many operating constraints (Thangaraj et al. 2010). The operating time of DOCRs is based on pickup current (Ip) or plug setting (PS) and time dial setting (TDS). The right selection of these settings is a very important concern for optimal coordination of DOCRs (Tjahjono et al. 2017). The reliable coordination of DOCRs means that the primary relay should isolate the faults in its own zone quickly to limit the system outage to the smallest area, and the backup relay should be operated after a specified time delay to clear the fault in case of primary relay failed to operate (Amraee 2012). Hence, the main goal of optimal coordination of DOCRs aims to minimize the summation operating time for all relays with maintaining the coordination time margin between relays pair (Chelliah et al. 2014).

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Optimal Coordination of Standard and Non-Standard Direction Overcurrent Relays Using an Improved Moth-Flame Optimization

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ABSTRACT In this paper, an efficient optimization technique, called improved moth-flame optimization (IMFO) is proposed to improve the performance of conventional Moth-flame optimization (MFO). Then, both of MFO and IMFO are applied to solve the coordination problem of standard and non-standard directional overcurrent relays (DOCRs). In the proposed IMFO, the leadership hierarchy of grey wolf optimizer is used to improve the performance of conventional MFO with the aim of finding the best optimum solution. The major goal for optimal coordination of DOCRs is to minimize the total operation time for all primary relays as well as satisfy the selectivity criteria between relay pairs without any violation in the operating constraints. The performance and feasibility of proposed IMFO are investigated using three different networks (8-bus network, 9-bus network, and 15-bus). The proposed IMFO is compared with conventional MFO and other well-known optimization techniques. The results show the effectiveness of the proposed IMFO in solving both standard and non-standard DOCRs coordination problems without any violation between primary and backup relays. In addition, the results show the power of proposed IMFO in finding the best optimal relay settings and minimizing the total operating time of relays which its reduction ratio reaches more than 28% with respect to the conventional MFO. Furthermore, the reduction in the total operating time of primary relays reaches more than 50 % with the usage of the non-standard relay curve.

INDEX TERMS Direction overcurrent relays, optimal coordination, improved moth-flame optimization, standard and non-standard relay curves, coordination time interval.

I. INTRODUCTION

Protective relays play an important role in saving continuity of the electric power network. The main goals of a protective relay are to isolate only fault part quickly, keep healthy parts in service, and maintain the reliability of the electric network. DOCRs are generally applied in the protection of distribution networks and sub-transmission networks [1]. DOCRs initiate when the current magnitude exceeds a predetermined value (pickup current) and flows in front of the relay [2]. The coordination problem of DOCRs is considered as a non-linear optimization problem with many operating constraints [3]. The operating time of DOCRs depends on pickup current (Ip) and time dial setting (TDS). In optimal coordination of DOCRs, the right chosen of these settings is very important [4]. The primary relay shall isolate faults quickly in its own area to minimize the system outage to the smallest area. After a specified delay time, backup relays shall be initiated to clear the fault in case of primary relays failed to work [5]. Hence, the main goal of optimal coordination of DOCRs aims to minimize the summation operating time for all relays and keep a time margin between backup and primary relays [6]. Different methods have been reported to find the optimal solution for relays coordination problem. Many heuristic methods were suggested to solve the coordination problem. The trial-and-error method was

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ORIGINAL ARTICLE

Development and application of an efficient optimizer for optimal coordination of directional overcurrent relays

Salah Kamel[1,3] · Ahmed Korashy[1,2] · Abdel-Raheem Youssef[4] · Francisco Jurado[2]

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Abstract

This paper proposes an enhanced version of grey wolf optimizer (EGWO) to solve the coordination problem of directional overcurrent relays (DOCRs). The EGWO is proposed to improve the convergence characteristics and computation time of the conventional grey wolf optimizer (GWO) by selecting a suitable balance between exploration and exploitation phases. This balance is achieved by exponential decreasing of the control parameter during the iterative process. The EGWO is explored in all search space during predetermined iterations, and then it fast converges to the best optimal solution by local exploitation around the optimal solutions. The proposed optimization technique is applied to solve the coordination problem of DOCRs. The main objective of optimal coordination of DOCRs is to minimize total operating time of all primary relays with sustaining the selectivity between relay pairs. The feasibility and performance of the proposed technique for solving the coordination problem of DOCRs are investigated using four different systems, compared with several well-known techniques. The obtained results prove the effectiveness and superiority of the proposed technique compared with these techniques. The proposed technique is able to find the optimal relay settings and minimize the total operating time of relays (with a reduction ratio about 19.3995% relative to the conventional GWO) without any miscoordination. In addition, DIgSILENT PowerFactory is used to validate the proposed technique.

Keywords Directional overcurrent relays · Optimal coordination · Coordination time interval · Enhanced grey wolf optimizer

1 Introduction

The complexity of power system operation is increasing as the size of the power system is increasing rapidly. Protection relays play an important role in keeping the reliability of power system at a high level [1]. The main objective of a protective relay is to identify and isolate the faulted elements and keep the non-faulted elements in service or, at least, minimize damage in the system due to abnormal conditions [2]. DOCRs are generally applied in the protection of sub-transmission and distribution systems [3]. DOCRs calculate the direction of a fault by comparing the phase angles of currents, or the phase angle of a current with that of voltage to determine the direction of a fault [4]. DOCRs operate when the current magnitude exceeds a reference current (pickup current) and flows in front of relay [5]. If the fault is located behind the relay, then no action will be taken [6]. The operating time of DOCRs is based on pickup current (Ip) or plug setting (PS) and time

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Hybrid Whale Optimization Algorithm and Grey Wolf Optimizer Algorithm for Optimal Coordination of Direction Overcurrent Relays

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CONTENTS

Abstract—In this article, a new hybrid metaheuristic optimization algorithm is proposed to solve the coordination problem of directional overcurrent relays (DOCRs). The proposed algorithm is constructed using hybrid whale optimization algorithm and gray wolf optimizer (HWGO) that enhance the performance and reliability of the traditional whale optimization algorithm (WOA). The proposed method enhances the exploitative phase of the WOA using a leadership hierarchy of the gray wolf optimizer (GWO) to find the best optimum solution. The coordination problem of DOCRs is subject to numerous constraints. The goal function for optimal coordination of DOCRs aims to minimize total operation time for all primary relay without violation in constraints to maintain reliability and security of the electric power system. The effectiveness of the proposed algorithm has been investigated on four different interconnected networks. The results using HWGO algorithm are compared with the original WOA, GWO, and earlier reported results of other optimization techniques. The results prove the viability of the proposed algorithm to solve the DOCR coordination problem and the ability of the proposed algorithm to overcomes the drawbacks and cover the weakness of the conventional WOA.

1. INTRODUCTION

Protective relays play the critical role in saving reliability and continuity of the power system. Directional overcurrent relays (DOCRs) are widely used in distribution and sub-transmission system protection [1]. The coordination of DOCRs is considered non-linear optimization problem with many operating constraints [2]. The optimal coordination of DOCRs is a very important issue for any protection system [1]. The operating time of DOCRs depends on time dial setting (TDS) and pick up current (Ip) or plug setting

Keywords: optimal coordination, whale optimization algorithm, gray wolf optimizer, direction overcurrent relays, coordination time interval

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uemp.

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Modified water cycle algorithm for optimal direction overcurrent relays coordination

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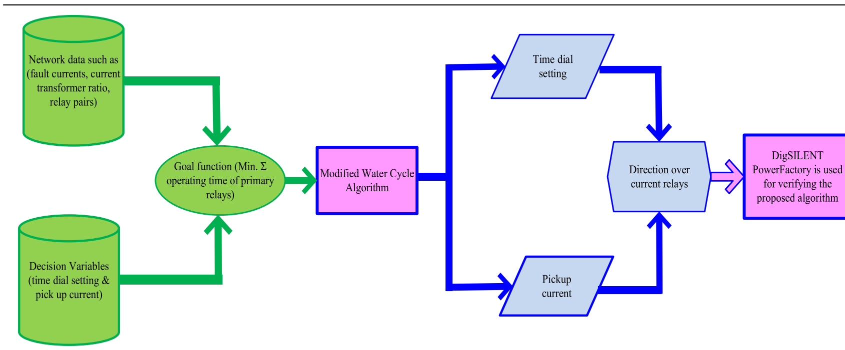
HIGHLIGHTS

- Optimization model of directional ov -er current relays coordination.
- Modified version for Water Cycle Algorithm.
- The main objective is to minimize the operating times of all relays.
- Time dial setting and pickup current setting or plug setting.
- Balance between explorative and exploitative phases.

GRAPHICAL ABSTRACT



Graphical abstract for solving DOCRs coordination problem using modified water cycle algorithm

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Modified Water cycle algorithm

ABSTRACT

The optimization model of Directional Over Current Relays (DOCRs) coordination is considered non-linear optimization problem with a large number of operating constraints. This paper proposes a modified version for Water Cycle Algorithm (WCA), referred to as MWCA to effectively solve the optimal coordination problem of DOCRs. The main goal is to minimize the summation of operating times of all relays when they act as primary protective devices. The operating time of a relay depends on time dial setting and pickup current setting or plug setting, which they are considered as decision variables. In the proposed technique, the search space has been reduced by increasing the C-value of traditional WCA, which effects on the balance between explorative and exploitative phases, gradually during the iterative process in order to find the global minimum. The performance of proposed algorithm is assessed using standard test systems; 8-bus, 9-bus, 15-bus, and 30-bus. The obtained results by the proposed algorithm are compared with those obtained by other well-known optimization techniques. In addition, the proposed algorithm has been validated using benchmark DIgSILENT PowerFactory. The results show the effectiveness and superiority of the proposed algorithm to solve DOCRs coordination problem, compared with traditional WCA and other optimization techniques.

1. Introduction

The complexity of power system operation is continually increased due to its extension with years. Protection relaying plays

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