

SOUMITRI JENA

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EDUCATION

Indian Institute of Technology Roorkee

July 2015 - November 2019

PhD, Electrical Engineering

National Institute of Technology, Hamirpur

August 2013 - June 2015

Master of Technology, Power System.

CGPA 7.92

Biju Patnaik University of Technology, Odisha

September 2007 - August 2011

Bachelor of Technology, Electrical Engineering.

CGPA 7.51

THESIS

PhD:

Improved Schemes for Busbar and Breaker-Failure Protection

- Application of cutting edge numerical analysis for development of reliable and high speed busbar protection.
- Integrated busbar and breaker failure solutions.

M.Tech:

Power Loss Minimization in Distribution System using Network Reconfiguration in the Presence of Distributed Generation.

- Solving simultaneous network reconfiguration and DG installation problems.
- Optimal DG installation points have been determined by sensitivity analysis and optimal sizing of DGs is estimated by PSO.

TECHNICAL STRENGTHS

**Modeling and Analysis
Software & Tools**

PSCAD/EMTDC, MATLAB, Microsoft Azure ML, C, C++, Java
MS Office, Latex, Code Composer Studio (TI), Synchrowave (SEL)

ACHIEVEMENTS

- Achieved 98.52 percentile in Graduate Aptitude Test in Engineering (GATE)-2013.
- Ministry of Human Research Development (MHRD), GoI scholarship for M.Tech (2103-2015).
- Ministry of Human Research Development (MHRD), GoI scholarship for PhD (2015-2020).
- The Institution of Engineers, India (IEI) R & D grant-2017 (grant no. DR2017010).

CONFERENCES/ WORKSHOP ATTENDED

- Attended South-East Asia International Joint Research and Training Program for Renewable Energy and Sustainable Development in Aug-2017 at NTU, Taipei, Taiwan.
- Presented research paper at Asia-Pacific Power & Energy Engineering Conference (APPEEC-2017) in Nov-2017 at Bangalore, India.
- Presented research paper at 2019 IEEE PES General Meeting (PESGM-2019) in Aug-2019 at Atlanta, GA, USA.

PUBLICATIONS

SCI Journals:

1. S. Jena and B. R. Bhalja, "Development of a new fault zone identification scheme for busbar using logistic regression classifier," in *IET Generation, Transmission & Distribution*, vol. 11, no. 1, pp. 174-184, January 2017.
2. S. Jena, and B. R. Bhalja, "Numerical Busbar Differential Protection using Generalized Alpha Plane," in *IET Generation, Transmission & Distribution*, vol. 12, no. 1, pp. 227-234, January 2018.
3. S. Jena, and B. R. Bhalja, "A New Differential Protection Scheme for Busbar Using dq0 Transformation," in *Electric Power Components and Systems*, vol. 47, no. 4-5, pp. 382-395, May 2019.
4. S. Jena, and B. R. Bhalja, "Initial travelling wavefront-based bus zone protection scheme," in *IET Generation, Transmission & Distribution*, vol. 13, no. 15, pp. 3216-3229, August 2019.
5. S. Jena, and B. R. Bhalja, "A New Sampled Value-based Bus Zone Protection Scheme with dq-components," in *IET Generation, Transmission & Distribution*, (Under Review).
6. S. Jena, and B. R. Bhalja, and O. P. Malik "An Improved Breaker-failure Reset Algorithm based on Numeric Analysis," in *IEEE Transactions on Industrial Informatics*, (Under Review).

Conference Proceedings:

1. S. Jena and S. Chauhan, "Solving Distribution Feeder Reconfiguration and Concurrent DG Installation Problems for Power Loss Minimization by Multi Swarm Cooperative PSO Algorithm," in proceedings *2016 IEEE/PES Transmission and Distribution Conference and Exposition (T&D)*, Dallas, TX, May 2016, pp. 1-9.
2. S. Jena and B. R. Bhalja, "A new numeric busbar protection scheme using Bayes point machine," in proceedings *2017 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, Bangalore, November 2017, pp. 1-6.
3. S. Jena, B. R. Bhalja, and S. R. Samantray "A Fault Zone Identification Scheme for Busbar using Correlation Coefficients Analysis," in proceedings *2019 IEEE PES General Meeting (PESGM)*, Atlanta, August 2019, pp. 1-5.
4. S. Jena, and B. R. Bhalja, "Application of Wavelet Transform for IEC-61850 Based Busbar Protection," in proceedings *IEEE India Council International Conference (INDICON 2019)*, Rajkot, Gujarat, December 2019 (Accepted for presentation).
5. S. Jena, and B. R. Bhalja, "A New Differential Protection Scheme for Busbar using Teager Energy Operator," in proceedings *International Conference on Power Systems (ICPS 2019)*, Jaipur, India, December 2019 (Accepted for presentation).
6. N. Kothari, B. R. Bhalja, V. Pandya, P. Tripathi and S. Jena, "A Faulty Section Identification Scheme in Thyristor Controlled Series Compensated Transmission Lines using Superimposed Currents," in proceedings *International Conference on Power Systems 2019 (ICPS 2019)*, Jaipur, India, December 2019 (Accepted for presentation).

Patents:

1. S. Jena, and B. R. Bhalja, "Add-on device and its method to prevent breaker-failure mal-operation" in *Indian Patents, Application No: CRN080*, December 2019 (Application filed)

AREAS OF INTEREST

- Power System Protection
- Substation Protection and automation
- IEC-61850 based substation applications
- Application of machine learning in Power System
- Microgrid protection and control
- Synchrophasor and PMU applications
- Power distribution systems

REFEREES

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Development of a new fault zone identification scheme for busbar using logistic regression classifier

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Abstract: This study presents the development of a new fault zone identification scheme for busbar using logistic regression binary classifier by utilising one cycle post-fault current signals of all the bays connected to the busbar. Practicability of the presented scheme has been verified by modelling an existing 400 kV Indian power generating station in power systems computer-aided design/electro-magnetic transient design and control software package. The presented scheme has been tested on enormous cases (38,400) which were generated by varying system and fault parameters. The proposed scheme provides effective discrimination between internal and external faults with a very high (99.69%) overall accuracy. Moreover, it remains stable in case of heavy through fault conditions particularly with current transformer saturation during which the conventional differential protection scheme mal-operates. Furthermore, it provides equally compatible accuracy for unknown system/unseen data set as well as for double/one-and-half breaker busbar arrangement. In addition, performance of the proposed scheme has been verified on the laboratory prototype and results are found to be satisfactory. The average tripping time is of the order of 23 ms in case of internal faults. At last, comparative evaluation of the proposed scheme with recently presented schemes in the literature indicates its superiority.

1 Introduction

Protection of busbar is very critical as clearance of bus fault would need the tripping of all the breakers of the bays (lines) connected to the faulted busbar. Such a tripping can potentially lead to widespread instability of a power system. Owing to increase in voltage level, complex configuration of busbar arrangements and extensive interconnection, stability of generators becomes an important condition which requires faster and reliable operation of the relay for a severe bus fault [1]. Therefore, it is important to develop separate busbar protection scheme which not only prevents hazards to the system but also minimises interruption of power by utilising a sectionalised and duplicated busbar arrangement. At the same time, it also prevents unwanted tripping of all the bays in case of heavy through fault. The high mega volt ampere (MVA) level associated with the bus zone area demands fast and reliable protection scheme for different busbar configurations [2–5].

Techniques for busbar protection are classified as non-unit protection and unit protection. The faults cleared by non-unit protection scheme which uses back-up overcurrent, earth fault and distance relays are usually found to be non-discriminative and slow in operation. Sometimes, busbar protection schemes are classified on the basis of the type of relays used such as directional relay and differential relay. Though the directional comparison scheme provides good classification in case of busbar faults, its reliability can be compromised by too many series contacts and complex circuitry. Moreover, an instantaneous overcurrent relay is required along with the directional relay to identify the existence of fault, which increases cost. A directional comparison-based busbar protection scheme was proposed by Zadeh *et al.* [6] that incorporate IEC61850 sub-station protocol and utilises superimposed components of currents. However, higher cost and increased complexity due to the requirement of voltage signals along with current signals are the prime limitations of the above scheme. Afterwards, Zou and Gao [7] proposed a busbar protection scheme based on travelling waves which distinguish internal faults with external faults. However, the

reliability of such a scheme has been reduced in a case when the transient fault signal is weak.

Afterwards, various wavelet transform-based digital protection schemes have been proposed [8–11]. Nevertheless, high-frequency noise signals during decomposition of current signals may reduce its accuracy. Subsequently, a new digital protection scheme for busbar is presented [12] which depends on comparison of relative phase angle difference of sequence components of currents. However, assembling sequence networks and their solutions is troublesome. Hence, a scheme based on symmetrical components may not be practicable. Afterwards, Chothani *et al.* [13] and Chothani and Bhalja [14] proposed fault zone identification schemes based on support vector machine (SVM) and relevance vector machine (RVM). However, the prime limitation of the above schemes is that they do not give satisfactory results due to the behaviour of the kernel function which needs to fulfil the Mercer's condition, and hence probabilistic predictions may not be feasible. Thereafter, Song and Zou [15] presented a busbar protection scheme by integrating the polarity of superimposed travelling-wave currents with a new phase-mode transformation matrix. Nevertheless, the above scheme fails to identify the fault zone in case of severe current transformer (CT) saturation and high resistance internal faults. Therefore, a new bus zone identification scheme using logistic regression (LR) classifier is presented in this paper. The authenticity of the proposed scheme has been estimated on large cases generated by varying fault and system parameters and also on unknown system/unseen data set.

2 System study

Fig. 1 shows the single line diagram of an existing 400 kV Indian power system. As shown in Fig. 1, three generators (S_1 , S_2 and S_3) are connected to the busbar through bays L_1 , L_2 and L_3 . The three CTs, installed on each bay, are used to acquire current signals. The line and system parameters can be referred from Appendix 1.

Numerical busbar differential protection using generalised alpha plane

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Abstract: This study presents a digital differential busbar protection scheme based on generalised alpha plane approach which combines the benefits of percentage differential approach and two-restrain alpha plane approach. The proposed scheme utilises one cycle current transformer (CT) secondary current signals of all the bays connected to the busbar to map the operating points on a complex alpha plane. The proposed scheme has been evaluated by modelling an existing 400 kV Indian power generating station in PSCAD/EMTDC software package. The performance of the proposed scheme has been evaluated on large numbers of cases with wide variation in system and fault parameters. In order to verify authenticity of the proposed scheme, a laboratory prototype of the proposed busbar protection scheme has been developed. From the developed prototype, CT secondary current signals are captured during internal faults and external fault with CT saturation condition. Comparison between the simulation and prototype results clearly shows the effectiveness of the proposed scheme in terms of higher sensitivity during internal faults and better stability in case of external faults. The proposed protection scheme has a high response speed (around 5 ms) and hence can be considered on par with modern busbar protection schemes.

1 Introduction

Busbar, in particular, is one of the vital parts of the power system as tripping of it causes disconnection of all associated transmission lines. On the contrary, any compromise in sensitivity can cause high replacement cost and forced alterations in system operations. Increased short-circuit level in an interconnected power system network and state-of-the-art smart grid infrastructure needs higher protection requirements. Therefore, it is highly desirable to achieve minimum fault clearance time. In fact, utilities have started mandating one-and-half cycle fault clearance time. The aforementioned reasons demand a faster and reliable operation of the relay [1–4].

Low-impedance percentage differential protection [5–7] is the long-established method used for the protection of power apparatus including the busbar. However, uncertain power system disturbances and close-in external faults with current transformer (CT) saturation may initiate false tripping of the above scheme. Moreover, it is unable to detect high-resistance in-zone faults due to insignificant magnitude of operating current [8]. Superimposed-impedance-based directional protection schemes [9–11] provide better stability against substantial CT saturation. However, due to the requirement of voltage signals along with current signals, the cost and complexity increases. In addition, the reliability of these schemes reduces in case multiple transmission lines connected to the busbar.

Schemes based on travelling wave [12–15] provide high-speed protection and are less prone to CT saturation errors. However, production of insufficient incident wave during faults with small inception angle, appearance of the incident and reflected waves at the same instant during close-in fault and requirement of dedicated CTs are the several limitations of the above scheme. Protection schemes based on wavelet transform [16–18] extract useful information from post-fault current samples and provide localisation in both time and frequency domains. However, these schemes do not provide good accuracy when the fault signal contains channel noise or DC offset. Though artificial intelligence (AI)-based techniques such as fuzzy logic and neural network [19] provide better fault zone identification accuracy, they require large number of neurons and tedious training process. Hence, application of AI-based techniques in busbar protection is still black boxes and

lacks transparency. Busbar protection schemes based on sophisticated machine learning algorithms like support vector machine and relevance vector machine provide good classification accuracy with diversified system parameters [20, 21]. However, probabilistic predictions are not feasible because of the abrupt behaviour of kernel functions. Moreover, on-chip implementation of the above schemes involves enormous complexity.

In this paper, a new generalised alpha plane (GAP)-based digital differential protection scheme for busbar is presented. The operating and restraining currents are computed by calculating the vector and scalar sum of current phasors of each bay. Afterwards, these currents are converted into equivalent incoming and outgoing currents using GAP approach. Finally, after calculating the ratio of equivalent outgoing and incoming current for each phase, they are mapped into the alpha plane.

2 Proposed busbar protection scheme

2.1 System study

Fig. 1 shows the single-line diagram of an existing 400 kV Indian power generating system. Three generating stations (S1, S2 and S3) are connected to the substation busbar through transmission lines (L1, L2 and L3), each with a physical length of 100 km. The simulation model is developed using PSCAD/EMTDC software package [22] and the transmission lines are modelled using 'Beregron model'. The line and system parameters are given in the Appendix.

2.2 Alpha plane characteristics

The concept of the alpha plane for differential protection of multi-terminal transmission lines was developed by Roberts *et al.* [23]. Primarily, the ratio of remote-end current and local-end current is calculated. In case of normal operating conditions/external faults, the ratio lies inside the restraining region, whereas it moves outside of the restraining region during internal faults. The concept of alpha plane is understood by a two-terminal line section as shown in Fig. 2a. Disregarding all possible errors, system non-uniformity, power angle and impedance non-homogeneity, the ideal alpha plane characteristics [24] are shown in Fig. 2b. As per (1), the

Initial travelling wavefront-based bus zone protection scheme

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Abstract: A high-speed busbar protection scheme based on initial travelling wavefronts is presented in this study. The aerial mode current travelling waves (TWs) across all lines connected to the busbar are calculated using Karenbauer transformation. Thereafter, the polarity and magnitude of wavelet transform modulus maximas of line current appearing after fault inception are analysed for fault zone and faulty phase identification. Its performance has been evaluated by modelling an existing 750 kV Indian substation in PSCAD/EMTDC software package. The simulation results reveal that the proposed scheme provides better stability for external faults and higher reliability in case of internal faults in comparison with conventional low-impedance busbar differential protection scheme (87B). Moreover, it remains immune to the current transformer saturation problems. In the end, comparative evaluation of the proposed scheme with the existing busbar protection schemes proves its superiority in terms of stability against external faults, sensitivity for internal faults, computational obligations, and communication requirements.

1 Introduction

Owing to the connection point of several substation devices, busbar is one of the most critical elements in a power system network. The occurrence of a fault on busbar may cause disconnection of all incoming and outgoing lines connected to the busbar. In large substations, busbar protection zone is usually divided into multiple zones [1, 2]. Therefore, implementing busbar protection has been one of the difficult aspects of power system protection. To achieve reliable protection of busbar, it is necessary to consider several aspects such as tripping time, stability, and sensitivity. High-speed tripping during bus fault is one of the most important requirements of busbar protection as it limits the widespread damage. To speed up fault clearance, the present practise is to reduce tripping time of the relay rather than developing new arc extinction methods for circuit breakers [3–5].

On the basis of the frequency components used in relay algorithms, busbar protection schemes can be broadly classified into two categories. The first category comprises schemes based on power frequency components. Since conventional busbar protection schemes are prone to current transformer (CT) saturation, most of the practical busbar schemes need phasor computation, which adds significant time delay in fault clearance. Directional protection schemes [6–8] are based on superimposed impedance, and hence require both acquisition and synchronisation of current and voltage data as per IEC61850 protocol. This, in turn, increases financial burden and decreases reliability. Moreover, synchronisation of current and voltage data is a major challenge as high-speed sampling is not feasible with coupling capacitor voltage transformers (CCVTs). Furthermore, the reliability of these schemes is further marginalised if the number of lines connected to the busbar is very high. Generally, 87B is the widely adopted busbar protection scheme for extra high-voltage (HV)/ultra-HV substations [9, 10]. However, these schemes are not fully immune to CT saturation problems. In such scenarios, the magnitude of the secondary current of the saturated CT is reduced and the phase angle is advanced. This develops a fictitious differential current subsequently leading to mal-operation. A busbar protection scheme using partial differential current has been presented in [11]. Although it effectively counters CT saturation effect, it significantly reduces the sensitivity during high-impedance faults.

The second category of protection schemes is based on transient frequency components. As these schemes are based on

instantaneous voltage/current, their tripping speed is significantly higher. The scheme reported in [12] provides a reliable solution by utilising the polarities of superimposed current at the relay location of all the lines connected to the busbar. As the magnitude of fault current is very small in case of high-impedance faults, it is difficult to identify the fault based on superimposed current. Hybrid approaches such as artificial neural network (ANN)-fuzzy [13] and wavelet-ANN [14] have been presented for busbar protection. Although they produce very high classification accuracy, a large number of neurones are required for a tedious training process. Moreover, any change in busbar architecture requires retraining of the algorithms. In the past, machine learning-based schemes for busbar protection [15–20] have been presented. Although these schemes provide high classification accuracy for diversified fault scenarios, it would be difficult to achieve probabilistic predictions because of the abrupt behaviour of the kernel or cost functions. Moreover, on-chip implementation of the complex algorithms introduces enormous difficulties. Busbar protection schemes based on alienation coefficients have been proposed in [21, 22]. As these schemes work on the static equivalent model of the busbar, any dynamic changes in busbar configuration make them infeasible.

The travelling wave (TW)-based scheme presented in [23] provides real-time high-speed protection. As the fault is identified before the starting of CT saturation, the mal-operation in these cases can be avoided. However, faults occurring at a close-in distance from busbar could not be detected as it practically results in zero voltage across the faulty phase(s). Wavelet transform (WT)-based schemes [24–28] have been presented by researchers which extract a great deal of information about the fault characteristics from the transient components. However, these schemes are vulnerable to noise present in the high-frequency sampled data. Moreover, the computational burden on the communication channel is very high as they require instantaneous data to be communicated with a very high frequency. A centralised busbar and line protection scheme has been presented in [29]. It requires both synchronised voltage and current measurements. Hence, the reliability decreases whereas computational requirements are increased.

To overcome the aforementioned limitations, this paper presents a new busbar protection scheme based on the appearance of Initial Travelling Wavefront at the CT locations in all lines connected to the busbar. The proposed algorithm clearly distinguishes between internal and external faults by comparing the polarity and



A New Differential Protection Scheme for Busbar Using $d-q-0$ Transformation

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CONTENTS

1. Introduction
 2. Simulation of Different Busbar Configurations
 3. Proposed Algorithm
 4. Results and Discussion
 5. Conclusion
- References

Abstract—This paper presents a new differential protection scheme for busbar using $d-q-0$ transformation. The proposed method is based on derivation of operating and restraining currents by utilizing direct axis (d) component of current transformer (CT) secondary current signals of all bays. The dual slope relay characteristic (derived from the operating and restraining current) of the proposed scheme operates in conjunction with a CT saturation detection algorithm and hence, provides better stability during external faults with CT saturation. The performance of the proposed scheme has been evaluated by modeling a 400 kV substation with two different busbar configurations, namely Breaker-and-Half configuration (BHC) and single breaker double-bus configuration (SBDBC) in PSCAD/EMTDC software package. The proposed algorithm has been tested for various fault cases with diversified system and fault parameters. The proposed scheme is highly sensitive against in-zone faults even with a considerable value of fault resistance as the average fault detection time remains within one-and-half cycle. At the end, a comparative evaluation of the proposed scheme with the conventional bus differential protection scheme (87B) clearly indicates its superiority in terms of stability against close-in out-of-zone faults with CT saturation and sensitivity for high impedance internal faults.

1. INTRODUCTION

Busbar, a hub of power transmission or distribution network, plays a vital role in the reliable operation of the grid. Mal-operation of a busbar protection scheme not only damages the equipment connected to the busbar but also leads to widespread system collapse. This turns out to be a very costly affair in terms of repair of the equipment and forced alterations in system operations. Meanwhile, the inter-connected power system network and state-of-the-art smart grid infrastructure need higher protection requirements because of increase in short circuit levels. Therefore, it is highly desirable to achieve minimum fault clearance time. Due to increase in voltage and short circuit level, complex configuration of busbar arrangements and extensive inter-connection, the stability of generators becomes an important condition which requires faster and reliable operation of the relay for a severe bus fault [1]–[5].

Keywords: busbar protection, differential relay, CT saturation, $d-q-0$ components, bus configuration

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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.