Electrical Power and Energy Systems 118 (2020) 105788

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

# New adaptive coordination approach between generator-transformer unit overall differential protection and generator capability curves

Mahmoud A. Elsadd[a,*], Wael Yousef[b], Almoataz Y. Abdelaziz[c]

[a] Department of Electrical Engineering, Faculty of Engineering, Menoufia University, 32511 Shebin El-Kom, Egypt
[b] Power Generation Engineering and Services Company (PGESCO), Egypt
[c] Faculty of Engineering & Technology, Future University in Egypt, Cairo, Egypt

ARTICLE INFO

*Keywords:*
Differential protection
Synchronous generator
Generator protection
Generator capability curves
Power Transformer

ABSTRACT

This paper presents a new method to increase the reliability of the generator-transformer unit overall differential protection with use of the capability charts. The main objective of proposed method is preventing the false tripping under both heavy external solid-faults associated at Generator Step-Up Transformer (GSUT) HV Side and Unit Auxiliary Transformer (UAT) LV Side, load rejection either house load rejection or zero load rejection, and synchronization. Also, the proposed method simultaneously detects both faults at low voltage side of UAT where the fault current is very small and near to normal load current comparing to generator capacity and single-line-to-ground faults at GSUT Low voltage side (generator terminal) due to the transformer delta connection that isolates the zero-sequence component from the network side. The presented method is based on using adaptive setting (three selected settings) for the generator-transformer unit overall differential protection to raise the characteristic setting under the external fault, load rejection and synchronization and decrease the characteristic setting under internal high-impedance fault. The suitable setting is selected according to the location of the generator operating point inside the generator capability curves. The generator capability curves are divided into four operating regions, where each one has a different differential characteristic setting having dual-rate of change of the differential current. The four operating regions are normal load operation and high impedance internal fault; heavy external and internal faults; load rejection and synchronization; and at under excitation operation without faults, respectively. The real dynamic simulation of the power station has been conducted by ATP/EMTP software for the large steam turbine driven synchronous generator. Extensive simulation case studies for internal faults and system disturbances are investigated as well as practical recorded signals.

## 1. Introduction

The large thermal power generating units are a crucial source for producing electric power in any power grid. Therefore, various protective devices protect the thermal power generation plant (Synchronous Generator (SG)) and Generator Step-Up Transformer (GSUT) to minimize the possibility of occurring a damage, minimize the period and frequency of undesired outages, and then increase the power system stability [1,2]. The differential protection is the highest effective protection scheme to distinguish between normal operating conditions and internal faults. The generator-transformer unit overall differential protection function (relay 87O) is also designed to be a backup protection for the differential relays associated with SG, GSUT, and Unit Auxiliary Transformer (UAT) [2,3]. However, different real problems still encounter the protection system of the power plant [4,5]. During a North American grid blackout on 2003, 13 types of generating units' relays were unnecessarily tripped. This mal-operation led to lost 290 units which are around 52.7 GW [6]. Also, during a major system disturbance in western American in 1996, 22.9 GW are lost due to tripping different protective devices of the generation units. The cause of the tripping were 22 cases for power plant problems, 6 cases for excitation control/field problems, and around 35 cases of load rejection/power swing [6].

Several techniques were introduced to develop and implement a reliable primary protection for either Generator or Transformer, individually [7-21] and other techniques were introduced to develop and implement a reliable backup protection for generator-transformer unit [22-24]. The Artificial Neural Network (ANN) based techniques were presented in [7-9] to classify and detect the faults on generator stator winding. In [10] and [11], Fuzzy Logic- based techniques were

* Correspondence author.
*E-mail address:* mahmoud.elsadd@sh-eng.menofia.edu.eg (M.A. Elsadd).

https://doi.org/10.1016/j.ijepes.2019.105788
Received 18 March 2019; Received in revised form 23 October 2019; Accepted 13 December 2019

**Table 1**
Survey on relay manufacturers which are commonly used in power plants.

| Manufacture | Relay Series | Relay Type | Main Function | Reference |
|---|---|---|---|---|
| Siemens | SIPROTEC5 | 7UT82/85/86/87 | Transformer Differential Protection | [37,38] |
| | SIPROTEC4 | 7UT612/613/63 | | |
| | SIPROTEC5 | 7UM85 | Generator Differential Protection | |
| | SIPROTEC4 | 7UM61/62 | | |
| GE (Alstom) | GEN1 | MDP/CFD22A | Generator Differential Protection | [39] |
| | GEN2 | SR489 | | |
| | GEN3 | DGP–BA 0005 | | |
| | GEN4 | DGP–CA | | |
| | TR1 | STD15C/BDD15B | Transformer Differential Protection | |
| GE/AREVA | Multilin | 889 | Comprehensive Protection and Management (Generator and Transformer) | [40–42] |
| | Multilin | 745/345/T60/T35/845 | Transformer Protection System | |
| | MiCOM Agile | P642/P643/P645 | | |
| | Multilin | 489/G60 | Generator Differential Protection | |
| | MiCOM Agile | P346/P343/P344/P345 | | |
| Schneider (AREVA) | MiCOM | P543/P544/P545/P546 | Current Differential Protection Relay | [43] |
| | | P630C/P631/P632/P633 P634 | Transformer Differential Protection | |
| | | P343/P344 | Generator Differential Protection | |
| Schneider | Easergy P3 | P3T32 | Transformer Differential Protection | [44] |
| | | P3G32 | Generator Differential Protection | |
| Beckwith | | M-3425A | Generator Differential Protection | [45,46] |
| | | M-3311A | Transformer Differential Protection | |
| SEL | | SEL-587 | Current Differential Relay | [47] |
| | | SEL-300G | Generator Protection Relay | [48] |
| ABB | REG | REG670 | Generator Differential Protection | [49] |
| | RET | RET615 | Transformer Differential Protection | [50] |

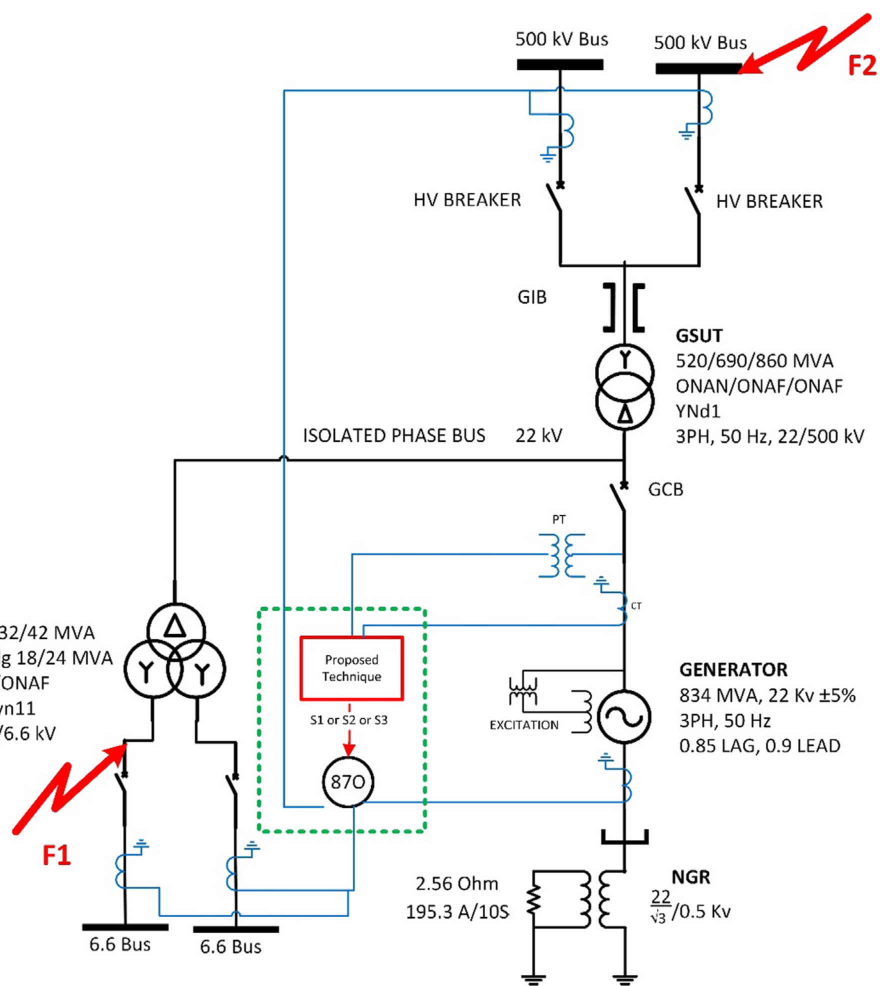


**Fig. 1.** The selected thermal power plant declaring the schematic of the proposed technique.