An Artificial Intelligence Based Approach for Bus Bar Differential Protection Faults Analysis in Distribution Systems

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ABSTRACT

The application of artificial intelligence approaches were introduced last decades in protection of distribution networks. These approaches started with introducing Fuzzy Inference System (FIS), then using Artificial Neural Network (ANN).

In this research, the application of Adaptive Neuron Fuzzy Inference System (ANFIS) for protection of bus bars will be illustrated. The ANFIS can be viewed as a fuzzy system, a neural network or fuzzy neural network. The objective of this research is firstly, to detect the fault occurrence on bus bar, secondly locating the fault. The fault detectors and locator are firstly trained using ANFIS technique and then they are tested in diversity of system conditions with respect to the fault types, inception instant, resistance and pre-fault conditions.

The fault detection unit used current magnitude difference change at fault and Pre-fault conditions for incoming and outgoing CTs. The testing data at different fault cases were not used before due to the training process of the controller. The output of the controller (Fault Index) was 0.999 for most fault conditions and 0.1065 at no fault condition. That means the percentage of error for ANFIS at fault condition is 0.1 % for most fault cases and almost zero for no-fault condition.

The fault location unit is the major element at this research, as it is the concerned unit for tripping signal sending. The fault location testing results are recorded at. The protection system selection depend on the time as the system should take the correct action at fault condition, sending correct tripping signal for internal fault conditions and prevent the mal-operation due to external fault conditions. On other hand, the fault clearing time is very important issue to avoid more damage at power system equipments. The fault location unit is tested at different fault cases not used before in the training process. The output of ANFIS controller was 0.999 for most internal fault cases and 0 for external fault cases. The system success to classify the fault location at different fault cases not used before in the training process with percentage error 0.1 % for most internal fault conditions and nearly to 0% for external fault conditions.
CHAPTER ONE

LITERATURE REVIEW
1.1 Introduction:

Bus bars are the most important component in a distribution network. They can be open bus bars in an outdoor switch yard, up to several hundred volts, or inside a metal clad cubicle restricted within a limited enclosure with minimum phase-to-phase and phase-to-ground clearances. Insulated bus bars are normally in small length sections and interconnected by hardware. Their form and electrical ‘node’ where many circuits come together, feeding in and sending out power as given in [1] and is presented in Figure (1-1).

![Figure (1-1): Schematic Illustrating Area Of Bus Bar Zone](image)

1.2 Bus Bar Fault:

In power system network, a bus is a connection point for many generation, transmission, or load circuits. If a fault occurs on a bus, all circuits which supplies the fault current, must trip to isolate the fault. A bus fault may result in considerable loss of service and severe system disturbance. Station arrangements are often designed to minimize the number of circuits that must be opened for a bus fault. As a result of improved continuity of energy supplies and flexibility of system operations, some power system stations use complex bus arrangements that increase demands for sophisticated bus protection schemes. Protection zone selection must be highly discriminative, such that a bus relay operates only for a protection zone fault. Protection of bus bar demands high standards. Failure to trip on an internal fault or false tripping of a bus bar during load service and external fault both have disastrous effects on the stability of power systems, and may even cause complete blackouts as given in [2].

Slow fault clearing results additionally in extensive damage at the fault location as a consequence of the generally high concentration of short circuit power at station.
buses. More than with other circuit protection methods intensified emphasis is therefore put on the essential requirements of speed and stability. A further important point to consider is through-fault stability with current transformer saturation as illustrated in [2].

1.3 The Requirements For Good Protection:

The successful protection can be achieved subject to compliance with the following as presented in [3]:

- a) Selectivity, trip only the faulted equipment.
- b) Stability, not to operate for faults outside the zone, most important for bus bars and stability must be guaranteed. Reasons for loss of stability are the interruption of Current Transformer (CT) circuits’ imbalance, or the accidental operation during testing.
- c) Tripping can be arranged two-out-of-two, zone and check relays.
- d) Speed, limit damage at fault point.

1.4 Bus Protection:

A bus, being a power system element that does not extend over long distances (as transmission lines do), is ideally suited for protection by a differential relay. Consider a bus and its associated circuits consisting of lines of transformers. The algebraic sum of all the circuit currents must be zero when there is no bus fault. With all circuit, CT ratios being equal, the secondary currents also add to zero when there is no bus fault. The various CT inaccuracies require that a percentage differential relay be used, but in this case the percentage slope can be quite small, as there are no mismatched ratios or tap changers to be concerned. Of course there is no magnetizing inrush phenomenon to be considered. One area of concern is the saturation of a CT during an external fault. Consider the fault at fault point in Figure (1-2). The current in the CT on this feeder is sum of all feeder currents, and consequently this CT is in danger of becoming saturated. A saturated CT produces no secondary current while the CT core is in saturation. Whenever the flux density crosses the saturation level, the secondary current becomes negligible. Under these conditions, the secondary winding is no
longer strongly coupled with the primary winding – the transformer essentially acts like an air-core device. A lack of strong coupling implies that the secondary winding presents very low impedance to any external circuit, connected as its terminals, instead of acting like a current source of high equivalent impedance. It should be clear that, if the secondary current in one CT becomes zero for any period during an external fault the differential current will be equal to the missing current causing the relay to trip. In general the core of a properly chosen CT should not saturate with in ½ to 1 cycle of fault inception as illustrated in [4].

However, often the requirement placed on bus differential relays is that they should restrain from operating for external faults even if a CT should saturate in ¼ cycle or less after the occurrence of a fault. This requirement places a very confining restriction on a computer based bus differential relay as explained in [4].

![Figure (1-2): Bus Protection With A Differential Relay](image)

However, analog relays have a very ingenious solution to the problem posed by a saturating CT since the saturated CT secondary appears as a low impedance path in the differential circuit, it is sufficient to make the relay a high-impedance device. The spurious differential current produced by the saturated CT then flows through its own secondary winding and by passes the relay having a much, higher impedance as given in [4].
1.5 Digital Bus Protection:

Computer relaying of bus bars attracted early attention, and then the interest flagged until recent times, when bus bars protection became a part of an integrated protection and control system for the entire substation. Bus protection in an integrated system seems particularly appropriate, as all the inputs needed for bus protection (currents in all Circuit Breakers (CB) and switches connected to the bus) are usually available within all other protection systems in the substation. Consider bus section 1 is illustrated in Figure (1-3), where the protection computers for line 1 and 2 and transformer 1 use the currents in circuit breakers CB1, CB2, and CB3. These current samples could be shared by their respective protection systems with a bus protection computer through computer-to-computer link. The questions of reliability and redundancy of equipment must be addressed separately as given in [4]. The bus protection system is dominated by consideration of the current transformer performance. First of all, bus differential relaying requires that all current transformers have identical turns ratios, an objective which is not easy to meet under all circumstances. Any mismatch between CT ratios must be compensated by auxiliary current transformers which add their own errors to the bus protection system CT mismatch error. In a computer relay, auxiliary current transformers are not needed as any main CT ratio mismatch could be corrected in software however a much more serious concern is the saturation of a CT for an external fault. The very elegant solution offered by a high impedance bus differential relay can not be used in a computer based protection system, as each current is acquired individually, no analog sum of the feeder currents is formed. This could of course be done, but would defeat a significant cost benefit that results from sharing the input information at the computer level. A new approach to the problem of bus protection in an integrated system must be found as presented in [4].
1.6 Feature For Bus Bar Protection:

Disregarding the problem of CT saturation for the moment, it is clear that a percentage differential relay, either based up on sample-by-sample comparison of all the currents, or upon current phasors can be used. The current phasors—having significant filtering—provide a sensitive and accurate relaying scheme. A combination of a phasor based and sample based percentage differential relaying schemes has been included as a component of the bus protection package in one commercially available system. The phasor based scheme could be used as long as there is no significant CT saturation, either early on during a fault before saturation sets in, or much later after the CT's come out of saturation. The transient monitor function is a convenient indicator of the state of the CT. A quarter cycle phasor calculation coupled with a quarter cycle transient monitor would provide a suitable computer based bus differential relay as illustrated in [4].

1.7 Thesis Objectives

The thesis objectives can be summarized as following:

a) Finding new differential protection system of bus bar more reliable and stable.
b) Solving the problems of the old differential protection system like CT saturation.
c) Combining between the Artificial intelligent and the differential protection of bus bar to create new age of protection system able to learn.

1.8 Thesis Organization

The thesis organized as following:

**Chapter one**: introduces the bus bar and its importance at power system.

**Chapter two**: Presents a literature survey about the modeling of differential protection on bus bar and the types of differential relaying for bus bars.

**Chapter three**: is handling the Artificial Intelligent (AI) techniques.

**Chapter four**: discusses a new suggested method for fault detection and location at bus bar, the different testing results at different fault cases and the results after using the artificial intelligent.

**Chapter five**: is showing the advantages of using the new technique for bus bar differential protection and a vision for the future works.
CHAPTER TWO

BUS BAR REPRESENTATION AND PROTECTION
2.1 Introduction:

This chapter presents a literature survey about the modeling representation and differential relaying of the bus bar. It is organized into three main sections. The first section focuses on the bus bar protection modeling in the power system simulation programs. Then, a general philosophy of the protective relaying is addressed in the second section. Finally, the last one deals with the differential protection, its principle of working and its function. Besides, the effects, and considerations that should be regarded when apply this type of protection on the bus bar.

2.2 Bus Bar Differential Protection Modeling:

The challenge of bus differential protection is due to Current Transformer (CT) saturation and ratio mismatch. The CT is the effective element at differential protection which effect on the efficiency of bus bar protection and may be lead to mal-operation of protection system. So the differential protection of bus bar modeling is regarding with CT modeling. The CT and relay modeling is practical tool to evaluate protection equipment performance as given in [5]. Software tools are used for CT and relay modeling (EMTP). The Alternative Transient Program (ATP) version of EMTP is the basic software tool for electrical system transient modeling. Figure (2-1) illustrates the equivalent circuit for CT and the CT model by ATP. The program ATP provides the graphical interface to EMTP on the MS-Windows platform. It can solve any single and multi phase network which consists on interconnections of linear and non-linear components. ATP library has many built in models including rotating machines, transformers, surge arrestors, transmission lines and cables. Ideal transformer, non-linear inductor and series resistance are used to construct the model of bus bar, current transformer and relay. The currents at both ends of bus bar are measured and stored in a file to be used for phasor estimation by MATLAB using DFT algorithm. Difference of these current phasors for fault and pre-fault conditions at both ends is taken and differential relay logic is used as presented in [6]. Appendix A introduces more details about ATP capabilities.
2.3 The Protective Relaying Philosophy:

Before introducing to the literature of differential protection of the bus bar, the protective relaying philosophy will be briefly introduced to clarify the function and the necessity of the power system protection. A power system is made up of interconnected equipments which can be said to belong to one of three layers from the point of view of the functions executed; this is exposed in Figure (2-2) as illustrated in [3&4].
Figure (2-2): Three –Layered Structure Of Power Systems

The basic level is the power apparatus which generates, transforms and distributes the electric power to the loads. Next; there is the layer of control equipment. This equipment helps maintain the power system, at its normal voltage and frequency, to generate sufficient power to meet the load and maintains optimum economy and security in the interconnected network. Finally, there is the protection equipment layer. The response time of protection functions is generally faster than that of the control functions. Protection acts to open and close circuit breakers, thus changing the structure of power system, whereas the control functions act continuously to adjust system variables without changing its structure of power system. The components of protection equipment are illustrated in Figure (2-3). The power instrumentation is provided by Potential Transformers (PT) and Current Transformers (CT). DC power is needed to supply relay power as well as to provide trip coil power for the power circuit breaker. Other inputs can modify relay behavior to speed up or inhibit operation as presented in [3].
Figure (2-3): Protection Equipment To Power system

2.3.1 Goals Of The Protective Relaying:

The purpose of power system protection is to make the production, transmission, and consumption of electrical energy as safe as possible from the effects of failures and events that place the power system at risk. Protective relaying cannot prevent faults, they can only limit the damage caused by faults. And as known, the fault is any condition that causes abnormal operation for power system or equipment serving the power system. Faults include: short circuits, open circuits, over voltages, elevated temperature, off-nominal frequency operation as discussed before. The objectives of the protection system can summarized as following [4]:

a) Maintain the ability to deliver electric power
b) Public safety
c) Equipment protection
d) Power system integrity and quality