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OPTIMUM COORDINATION OF DIRECTIONAL OVERCURRENT RELAYS USING TEACHING LEARNING BASED OPTIMIZATION ALGORITHM

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Abstract
Modern electrical power systems require dependable protection coordination to maintain secure and stable system operations. The distribution and interconnected power networks use Directional Overcurrent Relays (DOCRs) to identify abnormal current conditions and automatically disconnect damaged parts of the electrical system. The network requires proper relay coordination between primary and backup systems because this coordination enables selective fault clearing while preventing unnecessary disconnection of functional network segments. The process of establishing optimal relay settings for Plug Setting (PS) and Time Multiplier Setting (TMS) requires solving a complex nonlinear optimization problem because multiple constraints must be managed which include relay operating limits and coordination time interval (CTI) and system topology variations. The traditional relay coordination methods which rely on trial-and-error or graphical techniques require extensive time to complete and they fail to deliver optimal results in complex power systems that have extensive networks. This paper presents a detailed study on the optimal coordination of directional overcurrent relays using the Teaching Learning Based Optimization (TLBO) algorithm. The relay coordination problem is structured as a constrained optimization problem which seeks to minimize total operating time of primary and backup relays while preserving required coordination time interval between them. The TLBO algorithm which draws inspiration from classroom teaching and learning methods enables users to determine optimal relay parameters without needing to configure any algorithm-specific control settings. The proposed approach enhances relay coordination by decreasing relay operational time while it improves protection system selectivity and reliability. The results demonstrate that TLBO algorithm achieves faster convergence and better coordination results than traditional optimization methods which makes it appropriate for actual power system protection needs.
Keywords: Directional Overcurrent Relay (DOCR), Relay Coordination, Power System Protection, Teaching– Learning-Based Optimization (TLBO), Optimization Algorithms, Fault Detection, Coordination Time Interval (CTI), Distribution Power System.

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I. Introduction

The electrical power system functions as a complex interconnected network which includes generation units and transmission lines and substations and distribution systems. The system requires a protection scheme which can effectively detect and isolate faults to maintain its reliable and secure operation. Protective relays function as critical components which detect abnormal situations including short circuits and overloads and equipment malfunctions to protect electrical systems from harm and maintain power distribution. Power systems rely on overcurrent relays because these protection devices offer straightforward operation and dependable performance at an economical price [1]. The current flow direction in modern interconnected power systems changes based on network topology and multiple source presence. Directional overcurrent relays (DOCRs) serve as the main protection solution for these situations. The direct current of DOCRs uses both current magnitude and current direction to establish which part of the system experiences faults from the relay position. Directional relays function effectively in distribution networks which interconnect with different systems that use distributed generation sources [2].

The protection system requires proper protective relay coordination to achieve its intended selective operational function. The protection scheme requires its first relay to operate from the closest point to the fault while backup relays operate only when the primary relay fails to function. The system will maintain operational stability because only the affected area needs to be shut down. The system will experience multiple relay activations which lead to system outages when the relay settings lack proper coordination according to [3]. The success of relay coordination depends on choosing accurate relay parameters which include plug setting PS time multiplier setting TMS and coordination time interval CTI. Engineers must define these parameters so that primary relays will respond quicker than their respective backup relays while still achieving the necessary coordination requirements. Power system coordination faces increasing challenges because of the multiple relays which interconnect through various feeders and network configurations in large power systems [4].

The historical process of relay coordination required engineers to use both experimental testing methods and visual representation methods. The traditional methods provide straightforward implementation for users but become ineffective when used on extensive and intricate power systems. The methods established here do not guarantee the best relay configurations because they result in substandard protection outcomes. The development of optimization methods helps to find the best relay settings which meet operational requirements of the system according to [5]. The existing literature presents various mathematical and computational approaches which researchers use to address relay coordination challenges. The initial research used both linear programming and nonlinear programming methods to find the best relay configuration. The techniques need to simplify relay characteristics before they work properly because they lead to solutions that stop at local optimum points. The research community has begun to investigate artificial intelligence together with metaheuristic optimization methods as effective solutions for relay coordination challenges according to [6].

Researchers have used metaheuristic algorithms which include Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) and Evolutionary Programming (EP) and Differential Evolution (DE) to find the best settings for overcurrent relays. The techniques enable better search capabilities which allow them to solve nonlinear optimization problems that involve multiple restrictions. The research shows that these optimization algorithms can effectively decrease relay operational periods while preserving proper operational links between main and backup relays according to studies [7] and [8]. The Teaching Learning Based Optimization algorithm provides an effective solution for engineering optimization problems according to various optimization methods. The natural teaching and learning process in classrooms serves as the foundation for developing TLBO. The best solution in this algorithm functions as the teacher who helps other solutions to progress while learner interactions boost the search capabilities. The main benefit of

TLBO enables users to implement the system without needing special control parameters because this leads to faster system performance compared to other metaheuristic systems [9].

The TLBO algorithm has become a popular choice for researchers who want to optimize directional overcurrent relay coordination in power systems during the past few years. The results have shown that TLBO can effectively determine optimal relay settings while minimizing total relay operating time and satisfying coordination constraints. The algorithm also shows superior performance according to its speed and reliability metrics when compared to other optimization methods [10]. The study investigates the optimal coordination of directional overcurrent relays through the application of the Teaching Learning Based Optimization algorithm. The relay coordination problem requires a constrained optimization solution that aims to achieve relay time reduction while ensuring proper relay coordination between primary and backup systems. The proposed approach aims to improve the reliability, selectivity, and efficiency of power system protection schemes.

II. Literature Survey

The coordination problem of directional overcurrent relays has received multiple solution proposals from various researchers who have developed different methods to address this issue. The earliest research utilized mathematical programming techniques which included both nonlinear programming and linear programming methods to identify the best relay settings for their study. The research developed better relay coordination methods through the introduction of metaheuristic optimization techniques which included Genetic Algorithm, Particle Swarm Optimization, Differential Evolution, and Seeker Algorithm.

The algorithms enable better global search capabilities while they decrease the time required for relays to operate. The modern world has seen the development of Teaching Learning Based Optimization, Grey Wolf Optimization, and Harris Hawk Optimization as contemporary optimization methods that researchers use to enhance coordination efficiency and reliability. The algorithms enable the calculation of optimal relay parameters which include Time Multiplier Setting and Plug Setting while they maintain coordination requirements. Recent studies investigate the use of hybrid optimization techniques together with artificial intelligence methods to manage complex power systems that incorporate distributed generation and renewable energy sources.

Sr. No.	Author / Year	Method / Algorithm	Contribution	Limitation
1	A. J. Urdaneta et al., 1988	Non-linear Programming	First optimization approach for relay coordination	High computational complexity
2	D. Birla et al., 2005	Review of coordination techniques	Classification of relay coordination methods	Limited optimization analysis
3	P. P. Bedekar et al., 2009	Genetic Algorithm (GA)	Improved coordination of overcurrent relays	Convergence speed issues
4	Noghabi et al., 2009	Hybrid GA	Considered different network topologies	Increased computational effort
5	M. Mansour et al.,	Particle Swarm	Improved relay setting optimization	Sensitive to parameter

	2007	Optimization (PSO)		tuning
6	Manohar Singh et al., 2014	Differential Evolution Algorithm	Reduced relay operating time	Complex parameter selection
7	Amraee, 2012	Seeker Algorithm	Effective optimization for DOCR coordination	Computational complexity
8	Sueiro et al., 2012	Evolutionary Algorithm + LP	Improved coordination accuracy	Limited application scope
9	Singh et al., 2013	TLBO Algorithm	Efficient parameter-free optimization for relay coordination	Needs further validation in large systems
10	Kalage & Ghawghawe, 2016	Modified TLBO	Improved convergence performance	Increased algorithm complexity
11	Jamal et al., 2018	Grey Wolf Optimization	Better search capability for relay settings	Sensitive to initialization
12	Khurshaid et al., 2019	Firefly Algorithm	Improved optimization accuracy	Computational overhead
13	Sarwagya et al., 2020	Sine Cosine Algorithm	Enhanced relay coordination in distribution networks	Limited real system validation
14	Irfan et al., 2021	Harris Hawk Optimization	Adaptive relay coordination considering network changes	Algorithm complexity
15	Ramli et al., 2021	PSO + Linear Programming	Improved protection coordination with multiple curves	Higher computational time
16	Al-Muhaini et al., 2022	Optimization for renewable integrated grids	Coordination considering renewable generation	Increased model complexity
17	Korashy et al., 2023	Multiple optimization algorithms	Comparative analysis of different optimization techniques	Algorithm selection challenge
18	Foqha et al., 2023	Hybrid Optimization Algorithm	Improved DOCR coordination efficiency	Requires advanced tuning
19	Abdullah et al., 2025	GA and PSO hybrid approach	Improved coordination in distribution networks with DG	Increased computational effort)

20	Recent research (AI based)	Deep learning / reinforcement learning	Adaptive relay protection for modern grids	Requires large training datasets

III. Proposed System

The system architecture design employs Teaching Learning Based Optimization (TLBO) algorithm to achieve optimal Directional Overcurrent Relay (DOCR) coordination in power distribution networks. The power system network is first modeled with buses, transmission lines, and protective relays to analyze fault conditions. The system uses current transformers to continuously monitor current distribution across feeders which generates input signals for directional overcurrent relays. The relay system identifies a fault when it detects current that exceeds normal operational level in both magnitude and direction which it transmits to the optimization module.

The relay coordination problem is formulated as an optimization problem where the objective is to minimize the total operating time of primary and backup relays while maintaining the required coordination time interval (CTI). The TLBO algorithm is used to find the best relay parameters which include Plug Setting (PS) and Time Multiplier Setting (TMS). The algorithm functions through two phases which include teacher and learner phases to achieve better solutions through multiple improvement cycles. The optimized relay settings deliver faster fault detection capabilities while maintaining correct relay coordination and providing dependable protection for the power system.

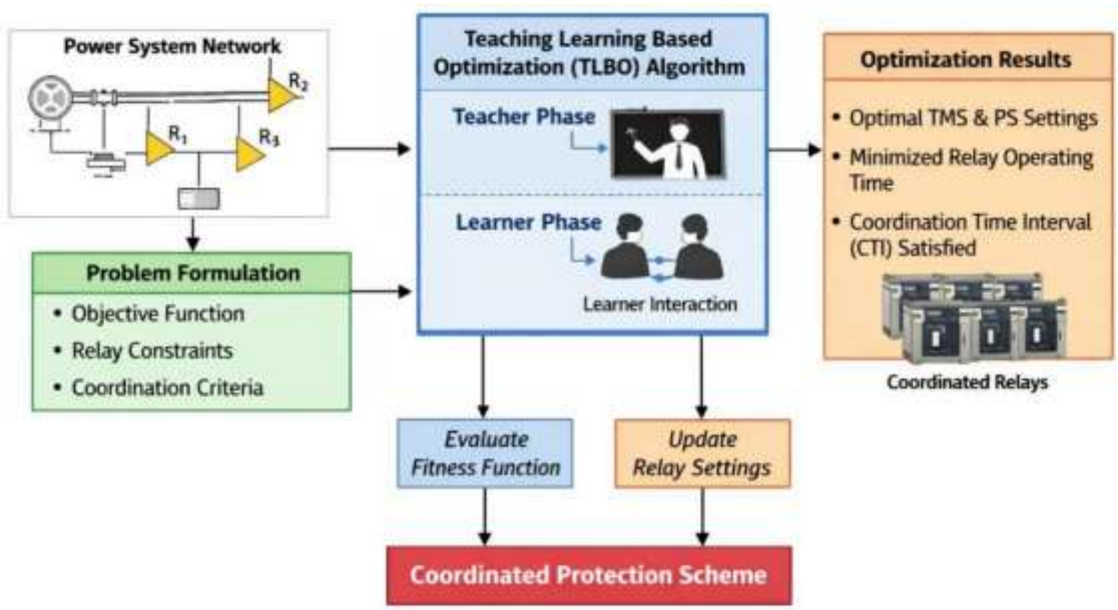

Fig.1. Proposed System

1. Power System Network Model

The electrical power distribution network of the system shows its components through the distribution of electrical power which includes buses and transmission lines and transformers and loads. The system model allows testing various fault conditions to study how power systems work during their nonstandard operating times. The network parameters need to include line impedance and load demand and source capacity for accurate assessment. The model provides all essential system information which engineers need to create relay coordination and optimization plans.

2. Fault Detection and Current Measurement

The block uses current transformers (CTs) to measure the fault current which flows through the transmission lines and feeders. The fault condition causes current flow to rise above its normal operating level. The current values which researchers measured are sent to the relay protection system for the system to monitor them continuously.

3. Directional Overcurrent Relay (DOCR)

The Directional Overcurrent Relay detects faults through its ability to measure both current magnitude and current directional movement. The relay operates when the measured current exceeds the preset threshold value. The system uses this method to establish fault location which handles faults that occur within the forward direction of the relay protection zone. The relay sends a trip signal for protective zone faults which causes the system to isolate the defective power system area.

4. Relay Setting Parameters

The performance of DOCR mainly depends on two important parameters:

Plug Setting (PS): This parameter establishes the current level which the relay needs to detect for activation. Time Multiplier Setting (TMS): This parameter establishes the duration which the relay needs to function.

The proper operation of primary and backup relays together with minimum time for fault resolution requires optimization of these parameters.

5. Teaching Learning Based Optimization (TLBO) Algorithm

This block demonstrates the process of optimization which identifies the optimal settings for relay operation. The TLBO algorithm replicates the teaching and learning methods that students experience within a classroom environment. The system operates through two distinct operational modes:

Teacher Phase: Thebest solution functions as the instructor who helps all population members reach better results.

Learner Phase: Students interact with each other to further improve their knowledge.

The algorithm produces optimal TMS and PS values which meet all requirements for relay coordination through its implementation.

6. Coordination Constraint Verification

This block checks the compliance of relay coordination requirements with established standards. The main constraint considered is the Coordination Time Interval (CTI) between the primary relay and backup relay. The CTI ensures that the backup relay operates only if the primary relay fails to clear the fault. The standard CTI value typically falls within the range of 0.2 seconds to 0.5 seconds.

7. Optimal Relay Setting Output

The algorithm produces its optimal relay settings which include TMS and PS values after completing the optimization process. The optimized parameters enable the relay to operate at its shortest time while achieving proper coordination of primary and backup relays.

8. Fault Isolation and System Protection

The protection system implements the optimized relay settings during the final block of the process. The relay uses its optimized settings to operate during a fault and isolate the defective area of the network. The system achieves higher reliability because it minimizes equipment damage and maintains constant power system performance.

TLBO Algorithm Flowchart

The optimization procedure which determines ideal relay configurations is depicted in the TLBO algorithm flowchart. The process begins with the initialization of a population of possible solutions which represent relay parameters through Time Multiplier Setting (TMS) and Plug Setting (PS) values. The fitness of each solution is evaluated based on the objective function that minimizes the total operating time of relays while satisfying coordination constraints.

The algorithm then proceeds through two main phases: the teacher phase, where the best solution improves the overall population, and the learner phase, where solutions interact and learn from each other to improve performance. The system implements its procedures repeatedly until it attains its designated stopping point. The algorithm establishes the most effective relay configurations which provide both operational system coordination and power system protection.

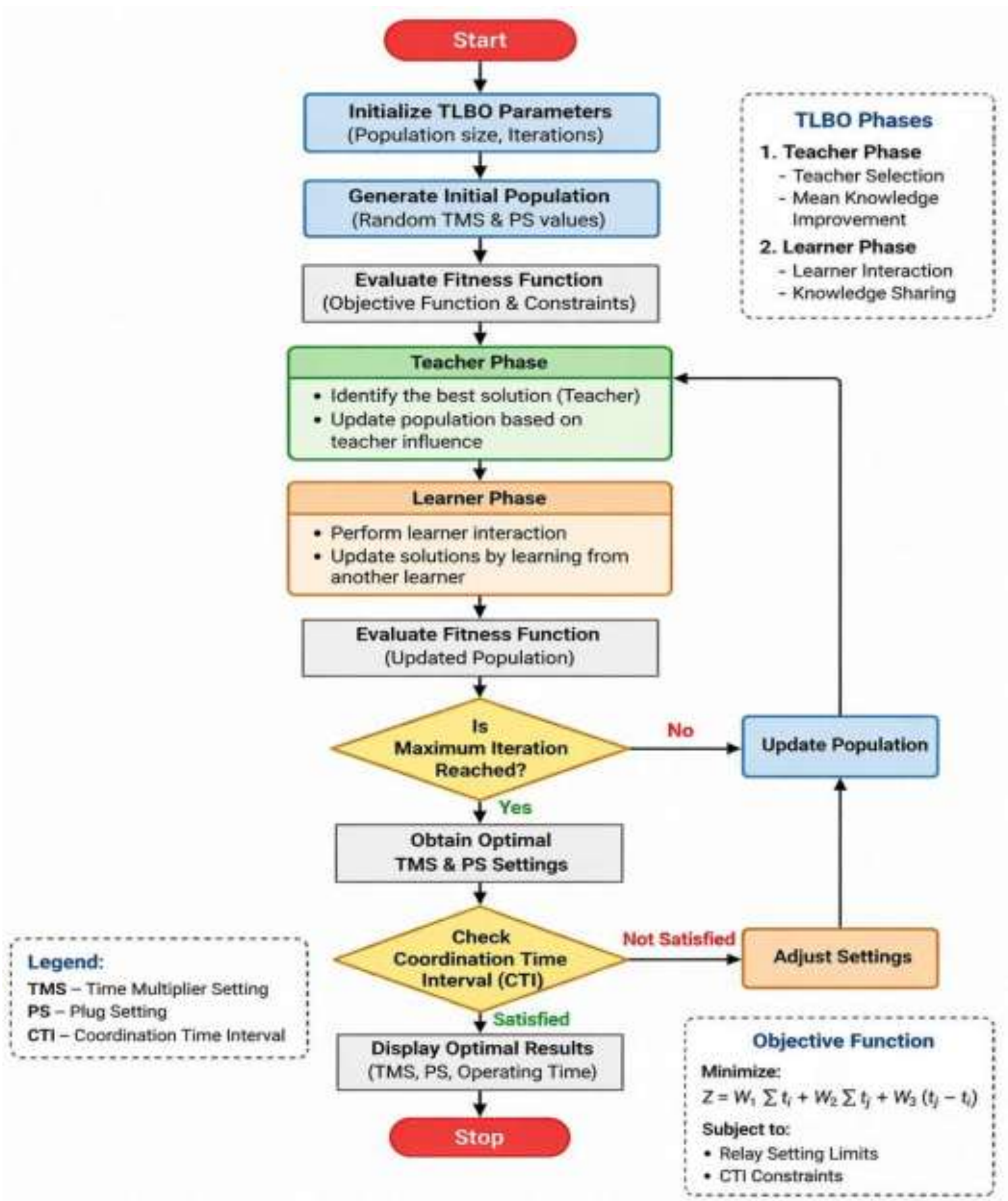

Fig.2. Flow Chart

IV. Conclusion

The paper examined optimal directional overcurrent relay coordination in power distribution systems through application of the Teaching-Learning Based Optimization (TLBO) algorithm. The protection system needs protective relay coordination because it establishes selective and reliable system operation while reducing fault effects on the complete network. Traditional relay coordination techniques use trial-and-error methods which require extensive time investment and fail to deliver optimal results for complicated power systems. The TLBO- based method developed by the team creates a relay coordination solution which uses optimization constraints to minimize primary and backup relay operating times while preserving necessary coordination time intervals. The algorithm employs teacher and learner stages to enhance candidate solutions until achieving optimal relay parameters which include Time Multiplier Setting (TMS) and Plug Setting (PS).
The results demonstrate that the TLBO algorithm can effectively determine optimal relay settings, reduce relay operating time, and maintain proper coordination among relays. The proposed method enhances protection system performance by increasing its reliability and selectivity and operational efficiency. The TLBO algorithm serves as an effective optimization method for modern power system relay coordination challenges.

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