Protection Methodoly for Supporting Distributed Generations with Respect to Transient Instability

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***Abstract*— Transient stability investigation plays an essential role in the restrictions of electrical energy systems. on the other hand, distributed generations (DGs) penetration rate determines the constraints of protection devices (PDs) setting in the electrical power network. Therefore, these two parameters should be considered the two main factors in the electrical protection of the network. This study examines the transient stability analysis of a power distribution grid with DGs to define the overcurrent relays' (OCRs) protection settings. To accomplish this goal, first, the DG´s transient stability is investigated for different fault places and different DG penetration rates. Then, the constraints of DGs are considered in the protection coordination of OCRs. For this purpose, a novel technique is suggested to calculate the modified value of the overcurrent relay time dial setting (TDS). In fact, applying the proposed method not only maintains coordination between the overcurrent relays but also prevents the instability of the DG sources. The implementation of the suggested protection strategy is analyzed through numerical scenarios on IEEE 33-bus distribution system by ETAP Software. In addition, we identify potential essential future directions for research to improve the suggested method with the aid of artificial intelligence (AI) by considering the practical constraints.**

Keywords—Power system analysis; Overcurrent relays (OCRs); Distributed generations (DGs); Protection devices (PDs); Artificial intelligence (AI).

I. INTRODUCTION

There has been a considerable improvement in electric energy generation capacity all over the world as a result of rising electrical load demand. In light of this increasing demand, developed-world economies have begun to lean toward reducing load termination to the minimum possible [1,2]. Furthermore, power losses and voltage drops are substantial because energy plants are commonly built far from load centers. Distributed generation (DG) systems near load centers might be able to solve this problem [3,4]. In a distributed generation system, smaller or medium-sized generating units are established in close proximity to load centers in order to produce electricity [5,6]. One of the most crucial challenges in the field of energy systems is the protection of power distribution grids [7,8]. The overcurrent relay is one of the most common types of protection relays [9,10]. This relay can be programmed for either time or current settings. Relays can be properly tuned to help mitigate power distribution failures owing to system faults [11,12]. Since transient instability has been the root cause of many large-scale power outages, it is a major consideration in power system operation and planning [13,14]. Various kinds of transient instability have emerged as modern power systems have progressed through ever-increasing levels of interconnection, the adoption of novel technologies, and the execution of increasingly taxing duties under extreme stress. Different strategies for keeping DGs stable in power systems (particularly in the distribution system) have been suggested [15,16].

In [17], a probabilistic stability-restricted optimal configuration framework for a power distribution grid in the presence of photovoltaic-based DG and a small hydropower plant is described. This method simultaneously considers a wide range of uncertainties with correlation and small signal stability. The dynamic response of small-scale synchronous generators to system faults as well as its sensitivity to the system parameters are investigated in [18]. Additionally, a practical protective method that allows utilization of the existing overcurrent and under voltage relays is suggested, and the benefits and drawbacks of this method are discussed in detail. The optimal implementation of fault current limiters (FCLs) in a variable-configuration distribution network with DGs is evaluated in [19]. In this research, a proposed multi-objective optimization algorithm is used to maximize the remediation effect of FCLs while minimizing their total cost. The authors in [20], furnish a formulation of a stability-constrained protection coordination problem that integrates transient stability restrictions for the objective of selecting the best relay settings. This paper also compares the proposed strategies to the traditional approach of protection coordination. A double-inverse overcurrent relay feature is suggested in [21], to provide appropriate coordination while maintaining the stability of DGs. This procedure is simulated on an IEEE 33-bus distribution network equipped with squirrel cage induction generators and synchronous-based DGs.

Generator dynamics and protection system behavior have a significant impact on how power systems behave in crisis situations. After a significant event, the dynamics of the system, which are determined by the parameters of the generators, loads, and control equipment, have a significant impact on how the energy system behaves [22,23]. The transient stability of a distribution grid that incorporates DG for the coordination of overcurrent protection relays is examined in this paper by considering faults at various points throughout the power system. The overcurrent relays' settings then take the generators' limitations into account. The study was performed on the IEEE 33-bus standard test system Which includes four generators with different penetration coefficients. The simulation has been done in ETAP software.

This paper is structured as follows: Section II illustrates the proposed optimization algorithm. In Section III, the configuration of the studied test system is described. The simulation results are furnished in Section IV. Finally, this paper is concluded in Section V.

II. Proposed Algorithm

In this paper, normal inverse crew is used (α=0.14, β=0.02, γ=1). The proposed algorithm according to Fig. 1 includes the three steps: (1) protection studies in conditions of non-connection of sources, (2) transient stability studies in DG connection conditions and (3) simultaneous establishment of CTI and CCT. In the third case, there are two possible scenarios:

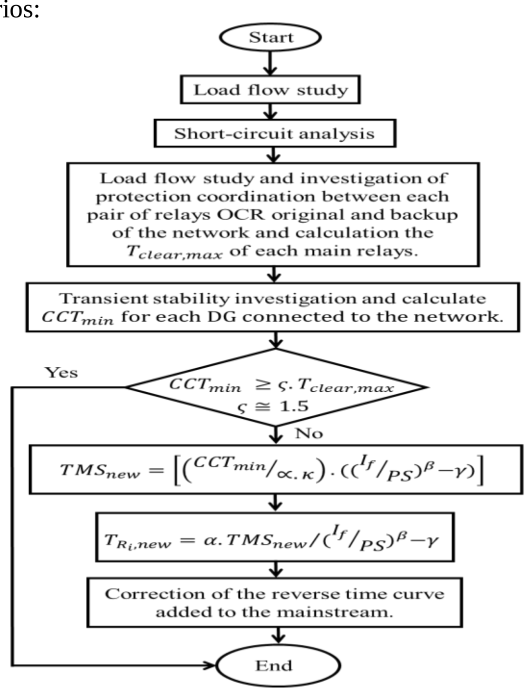

Fig. 1. Flowchart of the proposed algorithm

(a) Simultaneous establishment of CTI and CCT: In this case, there is no need to modify the protection settings. In other words, in this case, for the fault occurring downstream of the main relay, not only is the CTI between the two main relays and the backup and they are compatible with each other, but also before the DG instability between the two main relays and the backup fault occurs.

(b) Establishment of CTI constraint and non-establishment of CCT: According to the proposed scheme in this paper, in order to maintain the transient stability of DG, the operating time of the overcurrent relay should be modified. For this purpose, in the first stage, by reducing the TDS value of the overcurrent relay with the help of relations (3) and (4), an attempt is made to shift the reverse time curve of the mainstream overlay relay downwards so that both CTI and Establish CCT. The value of K in this paper is considered to be 1.5. Also, the minimum TDS value can be set to 0.01.

III. Network Under Study

The network studied in this paper to investigate the performance of the suggested strategy is IEEE 33-bus network [22,23], which is a radial grid. Base values are 50 MVA and 66.12 kV. In this network uses DG sources based on synchronous generators and the power level of each of these sources is 1 MWh. Buses 3, 9, 12 and 28 are intended for connecting DG sources. Load distribution, short circuit, protection coordination and stability studies have been performed in ETAP software. Based on the connection of distributed generation sources to the studied system, five cases are studied according to table 1. Therefore, for each DG, two additional relays are placed, one before (supporting relay) and one after (main relay) the DG installation location. Protection single line diagram is depicted in Fig. 1.

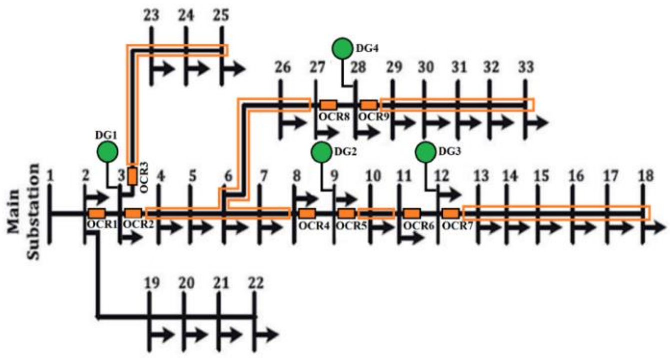

Fig. 2. Protection single line diagram for the studied network

IV. Simulation Results

In order to analyze the presented algorithm, simulation has been performed in the ETAP software environment that some of simulation results are shown in this section.

By making settings the typical mode and then checking the CTI value and if necessary, the TDS value, the backup overcurrent relays are corrected (increased) up in the presence of DG, to the CTI value is established. It should be noted that the maximum error resolution time of the system is 1000 ms [24]. The simulation outcomes of the protection coordination between overcurrent relays are shown in Fig. 3 for fault at bus 8 in first scenario, in Fig. 4 for fault at bus 25 in second scenario, in Fig. 5 for fault at bus 11 in third scenario, in Fig. 6 for fault at bus 18 in fourth scenario and Fig. 7 for fault at bus 33 in fifth scenario. The simulation results of the system are summarized for five cases studied in table 3.

Table 1. Different scenarios in the studied network

scenario	main protection	backup protection
1	OCR2	OCR1
2	OCR3	OCR1
3	OCR5	OCR4
4	OCR7	OCR6
5	OCR9	OCR8

As can be seen from the table, in the first, second, third and fifth scenarios to establish a CTI equal to and greater than 350 ms. But in the fourth scenario, due to the low error current, even with the reduction of the TDS value of the relays to the minimum adjustable value, 0.01, relays are not able to detect faults. Therefore, in addition to correcting the TDS value of the backup relay, the PS value of the OCR6 and OCR7 relays has been reduced to 0.6. In the fifth scenario, in order to limit the operating time of the backup relay to 1000 ms, the TDS value of the OCR8 relay is reduced.

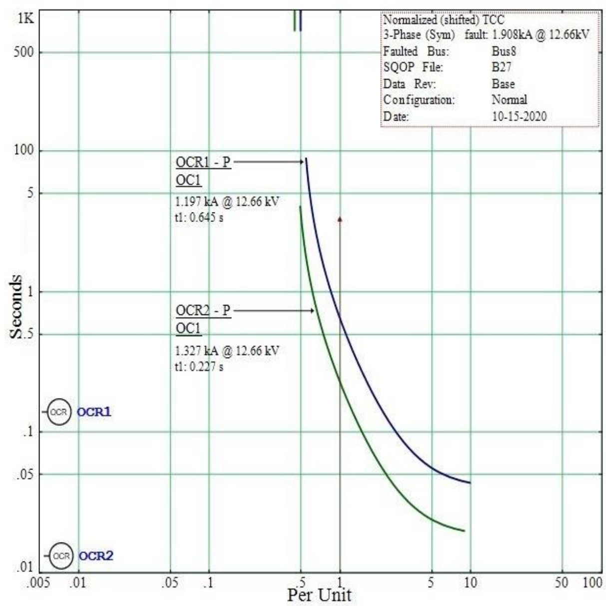

Fig. 3. Protection coordination between overcurrent relays for fault in bus 8 (first scenario)

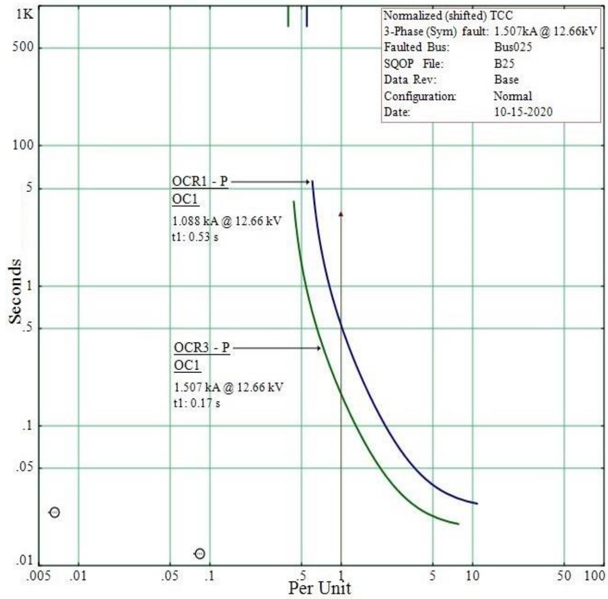

Fig. 4. Protection coordination between overcurrent relays for fault in bus 25 (second scenario)

But in the fourth scenario, due to the low error current, even with the reduction of the TDS value of the relays to the minimum adjustable value, 0.01, relays are not able to detect faults.

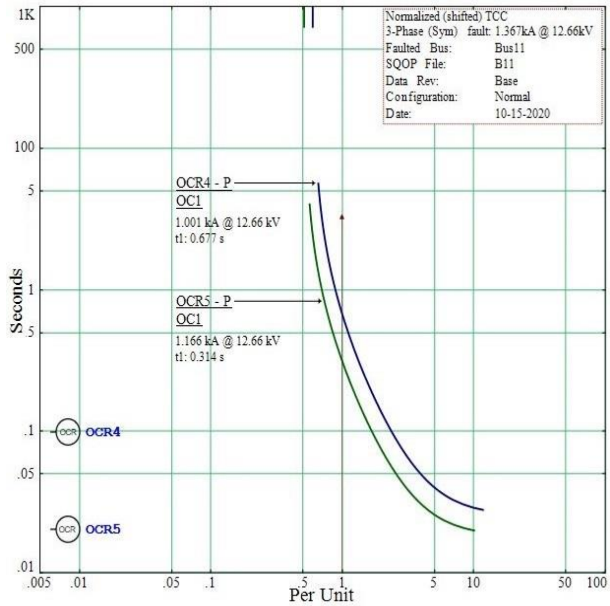

Fig. 5. Protection coordination between overcurrent relays for fault in bus 11 (third scenario)

Table 2. Protection simulation results of different cases on the test network

case	protection OCR backup	protection OCR main	time multiplier setting		PS of OCR backup and main	bus fault	performance time (ms)		CTI (ms)
			main OCR	backup OCR			main OCR	backup OCR	
1	OCR1	OCR2	0.1	0.22	1.2	B27	195	547	352
						B8	227	645	418
2	OCR1	OCR3	0.1	0.14	1.2	B25	170	530	360
3	OCR4	OCR5	0.1	0.14	1.2	B11	314	677	363
4	OCR6	OCR7	0.1	0.14	0.6	B18	296	653	357
5	OCR8	OCR9	0.07	0.07	1.2	B33	514	920	406

Table 3. Transient stability simulation results for different scenarios on the IEEE 33 Bus test network

case	protection OCR backup	protection OCR main	Fault bus	Maximum performance time of OCR	CCT (Msec)	CCT/K (Msec)	Establish a relationship (1)
1	OCR1	OCR2	B27	195	240	160	-
			B8	227			
2	OCR1	OCR3	B25	170	240	160	-
3	OCR4	OCR5	B11	314	510	340	✓
4	OCR6	OCR7	B18	296	380	253	-
5	OCR8	OCR9	B33	514	220	147	-

Table 4. Protection-stability simulation results of different scenarios on IEEE 33 Bus test network

case	protection OCR backup	protection OCR main	Fault bus	TMS (ms)		Performance time (ms)		CCT/K (Msec)	CCI (Msec)
				OCR backup	OCR main	OCR backup	OCR main		
1	OCR1	OCR2	B27	0.22	0.07	547	136	160	240
			B8			645	159		
2	OCR1	OCR3	B25	0.14	0.09	530	153	160	240
3	OCR4	OCR5	B11	0.14	0.1	677	314	340	510
4	OCR6	OCR7	B18	0.14	0.08	653	237	253	380
5	OCR8	OCR9	B33	0.07	0.02	920	147	147	220

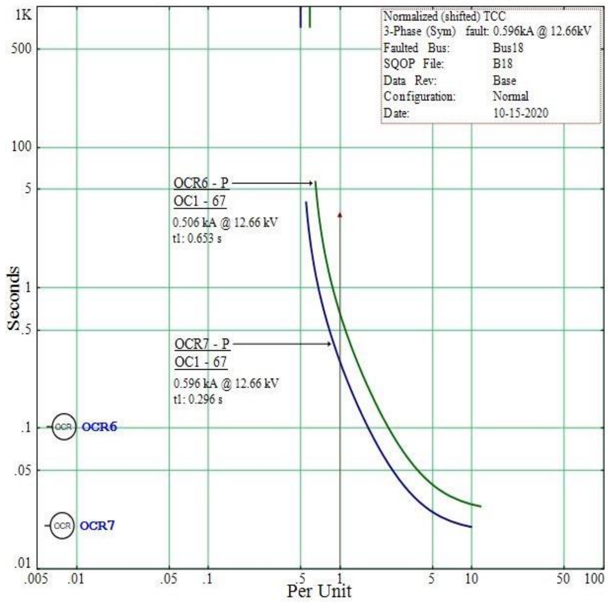

Fig. 6. Protection coordination between overcurrent relays for fault in bus 18 (fourth scenario)

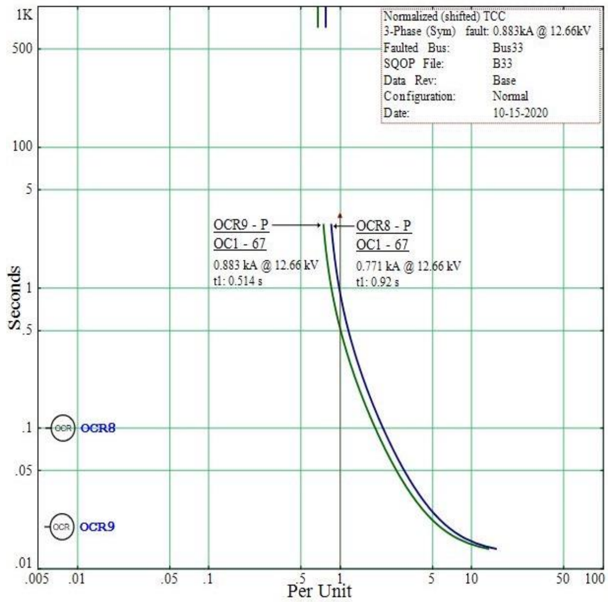

Fig. 7. Protection coordination between overcurrent relays for fault in bus 33 (fifth scenario)

Therefore, in addition to correcting the TDS value of the backup relay, the PS value of the OCR6 and OCR7 relays has been reduced to 0.6. In the fifth scenario, in order to limit the operating time of the backup relay to 1000 ms, the TDS value of the OCR8 relay is reduced.

In order to simultaneously establish the two limitations of CTI and CCT, it is necessary to simulate transient stability studies of DGs. A summary of the results of the simulation of protective coordination with the application of the CCT condition is given in the table (5) for different scenarios.

The results show that in this case the TDS value of the main relays is reduced to establish both CTI and CCT limit simultaneously.

The characteristics of transient stability of the modern power system will be substantially more complicated as a result of increasing levels of interconnection, increased integration of renewable energy, broad operation of power distribution systems, and liberalization of electricity markets. These modifications will cause several problems for traditional stability analysis and control approaches in terms of the speed and efficiency of the protection mechanism. In order to create strong and promising instruments for the next generation of the modern power system, the authors suggested updating the proposed protection mechanism with the aid of cutting-edge artificial intelligence (AI) technology. Since the proposed scheme can be easily implemented in the real power system, the novel AI-based methodology should avoid significant problems that AI-based method applications experience in practice, such as high data requirements, imbalanced learning, interpretability of AI, and robustness against attack.

V. Conclusion

In this paper, a transient stability analysis of a standard distribution network including synchronous generator DGs using ETAP software is presented. When a fault occurs in the electrical distribution system involving DG, if the fault is not rectified in time, the stability of the DG will be lost. Therefore, with the help of simulation results from transient stability studies, the critical time of fault clearance was extracted for all DGs connected to network for the worst fault conditions. The worst fault conditions in this case are three-phase faults at the location of the DG to the distribution system. In the first stage regardless of the CTI limit, the protection design was simulated for the worst fault conditions. The worst fault condition in any scenario is considered to be a three-phase fault at the end of the OCR protection zone. Then, the limitation of CCT on the protection plan is examined. It was shown that only in the third scenario, in addition to the CTI condition, the CCT condition was met. In other scenarios, both CCT and CTI conditions were established by modifying the TDS value of the overcurrent relay. In fact, in these scenarios, by reducing the amount of TDS in the overcurrent relay, the relay curve was shifted downwards and below the CCT value was generated scattered synchronous generator. According to the simulation results, in these conditions, not only did the CTI improve between each main relay and backup pair, but it also prevented the instability of scattered synchronous generator output.

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