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Optimization Techniques Based Adaptive Overcurrent Protection in Microgrids

Microgrids are the solution to growing power requirement of consumers at distribution level. The distributed generators (DGs) and loads in microgrid are connected or disconnected at any instant of time, resulting in reconfiguration of microgrid network. Thus conventional protection schemes are not applicable to microgrids. In this paper, the optimization of relay settings in microgrid is done using dual simplex algorithm. The significance of adaptive protection scheme is highlighted and the hardware model of Arduino based overcurrent relay is realized, tested and validated for microgrid application.

Keywords: microgrid protection; overcurrent relay; arduino; optimization algorithm.

1. Introduction

Distributed generator interfaced microgrids are a solution to meet the increasing power demand of consumers. The two modes of operation of microgrid are: grid connected and islanded mode. In grid connected mode, the utility grid caters to the load requirements. If a fault occurs in utility side, the microgrid transits itself into islanded mode. In islanded mode, the load demand is met by the DG's in the network. DG interface causes bidirectional power flow in microgrid and hence poses a key challenge to protection engineers in identifying suitable protection schemes. Few issues that occur in microgrid are: blind spot, nuisance tripping and variation in fault current magnitudes depending on the mode of operation of microgrid.

Reconfiguration in microgrid is triggered due to frequent connection and disconnection of DGs and loads. The conventional protection schemes are hence not suitable for microgrid. An adaptive protection scheme is a technique that is employed on microgrid for varying the relay settings based on the current topology and the mode of operation of microgrid. To handle this challenge [1] Kruskal aided Floyd Warshall algorithm is used for active node and shortest path identification from a faulted point to the point of common coupling in a microgrid network. For asymmetric fault identification, [2] the micro-grid is divided into several zones and negative sequence component is used as the characteristic quantity. The protection scheme is validated with EMTDC tool. A communication-aided protection scheme [3] with high selectivity using directional overcurrent relays based on intertripping and blocking transfer functions is employed on the microgrid. A novel monitoring technique [4] is utilized to identify fast transients and small variations of non-dispatchable photovoltaic devices and penetration level of RES. A hybrid microgrid protection system, which is a combination of traditional differential protection and adaptive protection scheme, is studied [5].

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Time multiplier setting (TMS) parameter of relay is optimized in order to achieve fast fault clearance in microgrid network [6]. The nondominated sorting genetic algorithm-II is used for optimal coordination of overcurrent relays [7]. To avoid mis-coordination of relays, the primary and backup relay combinations are fixed using LINKNET structure. Online coordination of directional overcurrent relay in interconnected power distribution is attained using Binary programming model [8]. The optimized settings are done using SCADA.

This paper analyzes how the optimization of relay settings in microgrid is done using dual simplex algorithm. The purpose of adaptive protection scheme is presented. The hardware prototype of Arduino based overcurrent relay is realized, tested and validated for microgrid application.

2. Notation

The notation used throughout the paper is stated below.

t_{op}	Time of operation of relay
t_{opj}	operating time for the primary relay at j, for a fault at j
t_{opjb}	operating time for the backup relay for a fault at j
λ	0.14
γ	0.02
PSM	Plug Setting Multiplier
t_{opj}	Time of operation of j'th relay
Minimum t_{opj}	Minimum time required for operation of the relay at j for fault at 'j'
Maximum t_{opj}	Maximum time required for operation of the relay at j for fault at 'j'
CTI or Δt	Coordination Time Interval
I_f	Fault current in Amperes

3. Problem formulation

The relay coordination problem is stated as an optimization problem. The purpose of this problem is to minimze t_{op} for the relays as indicated in (1).

$$\text{Min } z = \sum_{j=1}^{n} t_{opj} \tag{1}$$

The following are the constraints (2-5) that are met:
Relay Characteristic:
Inverse definite minimum time (IDMT) characteristics are assumed for all relays with suitable settings of λ and γ.

$$\alpha = \lambda /\{(PSM)^{\gamma} -1\} \tag{2}$$
$$PSM = I_f/(CT \text{ ratio} * \text{relay setting}) \tag{3}$$
$$t_{opj} = \lambda * (TMS) * \{(PSM)-1\}^{-1} \tag{4}$$
$$t_{opj} = \alpha(TMS) \tag{5}$$

From (5) and (1) the objective function is derived as:

$$\text{Min } z = \sum_{j=1}^{n} \alpha_j(TMS)_j \tag{6}$$

The value of TMS is hence determined.

Bounds on operating time :

$$\text{Minimum } t_{opj} \leq t_{opj} \leq \text{Maximum } t_{opj} \tag{7}$$

Coordination time interval:

CTI must be maintained between relays. The difference between the operating times of the primary relay and the backup relay must be greater than or equal to the CTI.

$$t_{opjb} - t_{opj} \geq \Delta t \tag{8}$$

3. Dual Simplex Algorithm

It is an economical approach as it converges with less number of iterations. This method solves only maximization functions. If the objective function is minimizing, the constraints should be $\leq$ type.

Steps:

1. Start
2. Initialize the objective function and constraints.
3. Add slack variable in objective function, to convert all inequality constraints to equality constraints.
4. Use basics and non-basics and form the Simplex table with basics and non-basics
5. Compute cost coefficient $C_j - \Sigma C_i e_{ij}$
6. The method fails, if cost coefficient is positive. Go to step 11.
Else
i. If at least one number in B column is negative then goto Step 6.
ii. Else if all B's are positive optimal solution is achieved.
7. The one with most negative B is called the leaving variable. Identify the leaving row.
8. No solution is available if all coefficients in leaving row are positive. Go to Step 11.
i. Else, max $[(\Sigma c_i e_{ij} - C_j) / a_{ij}]$ containing column is the entering column
9. Identify the pivot element and make changes in the entering row or column. Derive the updated table.
10. Go back to Step 5.
11. Stop.

3.1. Dual Simplex algorithm tested on 4-bus microgrid network

Figure 1: 4-bus microgrid network
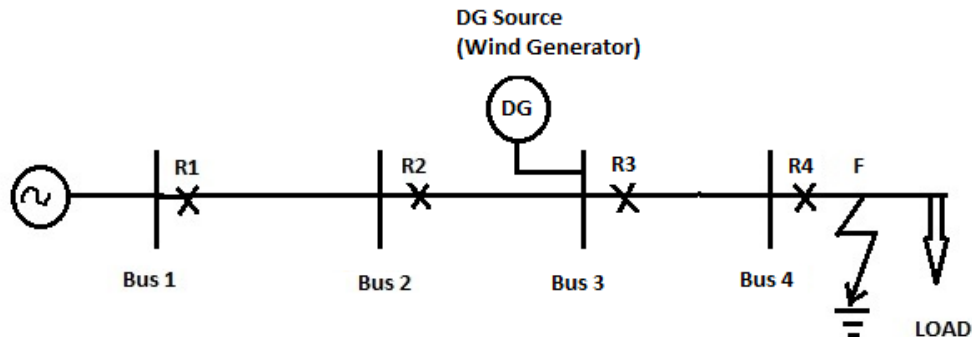
Four relays R1, R2, R3 and R4 with TMS values X1, X2, X3 and X4 are placed on the feeders as indicated in Figure 1. The optimized TMS values are as indicated in Table 1. The optimization techniques are hence critical to minimize the fault clearance time.

Table 1 : Optimized TMS of relays using Dual Simplex Algorithm

Time Multiplier Setting	X1	X2	X3	X4
Dual Simplex Algorithm	0.1219	0.1135	0.0492	0.1109

4. Adaptive protection in microgrid

4.1 Communication between Central Protection Center (CPC) and relay

In Figure 2, the central protection center continuously monitors the microgrid and is capable of communicating with the relays and DGs. By monitoring the relays, the central protection center is able to capture the current flowing in the feeders of the microgrid. It facilitates in identifying the fault current and the direction of flow of fault currents. This is a key parameter as microgrids are prone to bidirectional power flow and conventional protection schemes do not suffice the system. This feature of the CPC, aids in isolating the faulty part of network from the microgrid with minimum portion of network disconnection. The CPC captures the status of DG connection or disconnection from the network. The rated DG current ($I_{ratedDGx}$) and the pertaining contribution of fault current ($I_{faultDGx}$) are recorded by the CPC. The pickup current of the relay is computed using (9).

$$I_{relay} = (I_{faultgrid} * Operating\ Mode) + \sum_{j=1}^{n} (I_{faultDGj} + statusDG_i) \qquad (9)$$

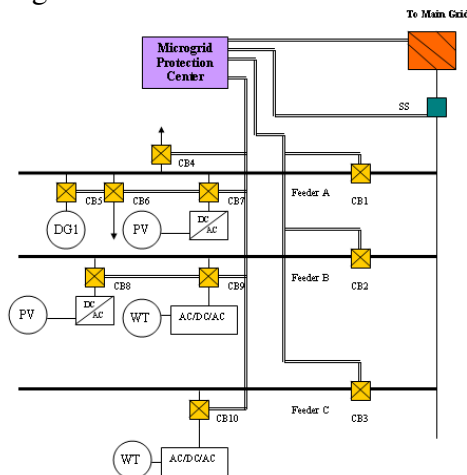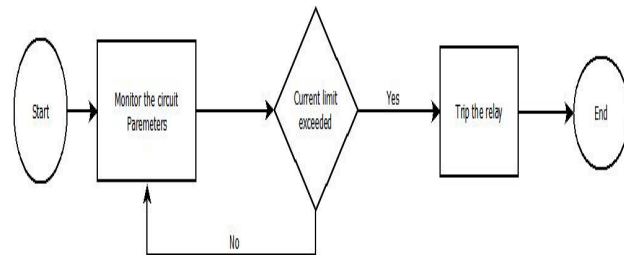Figure 2: Communication assisted Microgrid Protection Center

Figure 3: Algorithm modelled in Arduino based Overcurrent relay

4.2 Methodology

A prototype for the continuos monitoring of circuit parameters such as voltage and current is proposed and realized using Arduino Uno. Figure 3, indicates the algorithm that is realized by the Arduino based overcurrent relay. The algorithm is initially tested using Orcad PSpice. In this algorithm, the current in the feeder is continuosly monitored and compared against a threshold current. A fault is said to occur in the system, if the monitored current exceeds the threshold current. This trips the breaker connected to the system and glows the fault indicator LED. If there is no fault in the network, then the Normal Operation LED glows as indicated in Figure 4.

Figure 4: Arduino Based Overcurrent Relay Testing
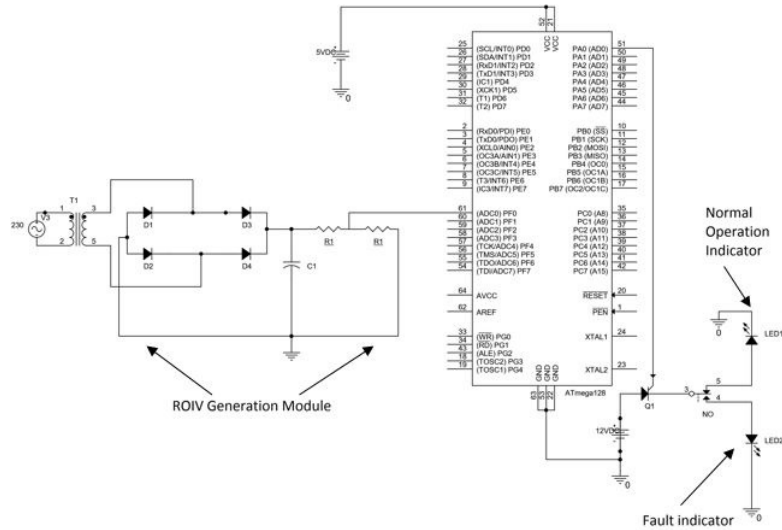
4.3 Hardware prototype

Table 2 provides the components required for building the Arduino based overcurrent relay prototype as indicated in Figure 5.

Table 2: Design Specification

S No.	Name	Rated Voltage (V)	Rated Current (mA)	Frequency (KHz)
1.	Transformer	230/12	500	0.05
2.	Diode (1N4007)	20	1000	-
3.	SCR (C106MG)	600	4000	50-60
4.	Microcontroller (ATMEGA 328P)	5	10	47
5.	Relay (Omron 4123)	12	5	-
6.	Capacitor (10uf)	63		

To realize the Arduino based overcurrent model, an input of range (0-230V) AC is passed as an input to the relative overcurrent input voltage (ROIV) generation module. This module steps down the input voltage using a transformer (T1) to the range of (0-12V) AC. This is fed to a full bridge diode rectifier, whose output is a positive voltage waveform which is compatible with the Arduino microcontroller. A smoothing capacitor (C1) is also connected in parallel to the bridge rectifier. A resistor array (R1) is used to further decrement the voltage, to provide a DC voltage called ROIV. Let 'Z ' be the feeder impedance.This voltage is fed to the Analog to Digital converter (ADC) of the Arduino Uno. The algorithm executed in the Arduino Uno converts the ROIV to a current called proportional feeder current (I_{PFC}) in the range of (0-5A). This current is then compared with a referential or threshold current (I_{TH}). If I_{PFC} exceeds I_{TH}, a fault is said to occur. Also a pulse is generated through the output port of the Arduino, which triggers the Silicon Controlled Rectifier (SCR). The SCR is given a 12V supply, which is connected to a 12V relay. This relay trips when there is a fault and the 'Fault Indicator LED' glows. During normal operation 'Normal Operation LED' only glows.

Pseudocode
1. Start
2. while TRUE
3. READ ROIV
4. I_{PFC} = ROIV/Z
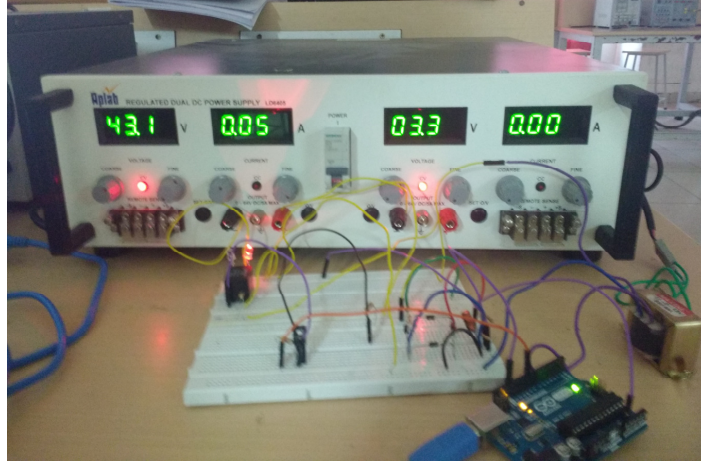5. if $I_{PFC} > I_{TH}$
        P0 = HIGH
6. End

Figure 5: Hardware Prototype of Arduino Based Overcurrent Relay

5. Conclusion

Conventional protection scheme are not suitable for microgrid due to bi-directional power flow and variation in fault current magnitude in the system. Adaptive protection is a solution to protect reconfigurable microgrids. To facilitate fast fault clearance in microgrid, optimization algorithms are used to optimize the TMS and time of operation of relays. This paper presents the implementation of Dual simplex algorithm on a 4-bus microgrid network, to optimize TMS values of relays. An arduino based Overcurrent relay is modelled, tested and successfully validated for a microgrid network.

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