Optimal Overcurrent protection for industrial medium voltage network

الوقاية المثالية لمرحلات التيار الزائد لشبكة صناعية ذات جهد متوسط

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الخلاصه:

قد تتسبب الأعطال غير الطبيعية في نظم القوى في انهيار الأجهزة والمعدات الكهربية مما يمثل خطورة بالغة عليها. ولذلك فإنه من الضروري الإهتمام بمنظومة الحماية وتوفير الحماية اللازمة لجميع المعدات مع إمكانية تعديل المنظومة القائمة في بعض الأحيان خاصة مع استخدام بعض العناصر الحديثة مثل وحدات التوليد الموزعة. كما تمثل عملية التنسيق بين وحدات الحماية المختلفة أهمية خاصة لتقليل زمن تشغيلها للحد الأدنى في ظل كثرة أعداد تلك الوحدات في منظومة التوزيع. ويهدف هذا البحث لتحديد عملية الضبط لوحدات الحماية بالصورة المثلي لتقليل زمن تشغيلها للحد الأدنى مع مراعاة جميع القيود الفنية اللازمة. وتم تطبيق الفكرة المقترحة والمعتمدة علي أسلوبي البرمجة الخطية والخوارزمات الجينية علي محطة كهرباء ذات جهد منخفض ومتوسط. كما تم مقارنة النتائج التي تم الحصول عليها بالنتائج الخاصة بالطرق التقليدية لبيان تفوق الطريقة المقترحة. وأثبتت النتائج دقة وفاعلية الطريقة المقدمة لتحقيق التنسيق الكامل بين وحدات الحماية وتقليل زمن التشغيل للحد الأدني.

Abstract

Abnormal condition and faults in power systems can cause power supply interruption and sometimes equipment damage. Hence, there is an increasing need for an effective protection scheme. In order to obtain a secure and reliable protection system, an effective coordination has to be satisfied between backup and primary protection devices. The main objective of this paper is to select the optimal settings of overcurrent relays that achieve the minimum operating time for relays when subjected to abnormal conditions or faults. The coordination process between overcurrent relays inside the network is accomplished considering detecting the fault and tripping the nearest circuit breaker to disconnect the affected area without affecting other areas. This paper investigates the protection requirement of switchgears in a practical power plant and design a coordination set for all circuit breakers and overcurrent relays in the low and medium voltage areas. In addition, both linear programming and genetic-algorithm methodologies are used to optimize the values of time dial setting for different operating scenarios of power plants so as to achieve the minimum operating times of overcurrent relays.

Index Terms- Genetic Algorithm, Linear programming, Overcurrent relay, Power plant switchgear, Protection Coordination

I. Introduction

The coordination of overcurrent relays represents a very important issue that is defined as “properly localizing a fault condition to minimize outage of equipment, by selecting the suitable fault protective device” [1]. The coordination of overcurrent relays depends upon the topologies of the protective system: mesh, industrial, network, etc… as well as the main elements forming coordination problem. Many publications discussed the coordination problem, where distinct types and techniques can be recognized for solving and formulating coordination problem statement.

The authors in [2] proposed merged genetic algorithm (GA) and linear

Received: 17 February, 2015 – Accepted: 14 April, 2015

programming (LP) to divide the optimization problem into two tasks. GA is used to solve the non linearity of the problem to obtain setting variables, while LP is used to obtain corresponding time multiplier setting “TMS” variables. This method is applied to an 8-bus system and provided accurate results.

Overcurrent coordination considering the priority of constrains is presented in [3]. The idea is to solve the coordination problem of overcurrent relays with associated constraints using weighting factors according to constraints priority that have to be satisfied. Expert rules are used to determine priority weights of the constraints. The application of this method provides good results with high flexibility, but it needs high experience.

The authors in [4] took into consideration time setting multiplier (TSM) and plug setting multiplier (PSM) of overcurrent relays in the optimization process. The proposed method has been tested on a network having 8 buses, one generator, 8 lines and 8 overcurrent relays using GA. The optimal coordination of overcurrent relays is formulated depending on TSM and PSM, where GA is used to calculate both of them simultaneously. On the other hand, the authors in [5] presented a powerful method by using GA to solve the coordination problem considering continuous and discrete time setting multiplier TSM and timw dial setting “TDS”. The proposed method is applied to two power system networks, one of them consists of 8 lines, 8 buses, one transformer and one generator, while the other network consists of 7 lines, 6 buses and 1 transformer. Acceptable results are obtained and the discussion ensured that the method is efficient, accurate and flexible for different power system networks. The authors in [6]-[9] and [10] presented different methods for overcurrent relays coordination but they considered TSM only. In these papers, the proposed methods to solve coordination problem involved deterministic and artificial intelligent methods such as GA. The above-mentioned papers concerned only with mesh networks. In [11], the authors presented proposed techniques based on nonlinear optimization algorithm to solve the overcurrent relay coordination problem of an interconnected power system.

In [11], the authors proposed a modified particle swarm optimizer for solving the coordination problem of overcurrent relays. Three case studies are presented and their results are compared to the results obtained by linear programming algorithm to show the capability of the proposed method.

This paper presents a methodology to optimize the settings of overcurrent relays by minimizing their operating time satisfying all operating constraints. A practical power plant is investigated and a coordination set for all overcurrent relays in the low and medium voltage areas is developed. Both the linear programming and GA are used to optimize the values of TDS for different operation modes to achieve the minimum operating times of overcurrent relays and their results are compared. The results ensure the capability of the optimization techniques to provide the optimal coordination considering all constraints with high accuracy.

II. Overcurrent Relay Coordination Problem

The main objective of setting overcurrent relays is to define the trip time and pickup current setting of each relay to obtain the minimum clearing time of primary relays. Therefore, the overall objective function can be written as follows:

$$\text{Min } J = \sum_{i=1}^{n} T_{ii} \qquad (1)$$

where, T_{ii} is the operating time of the primary relay close to the fault and n is the number of relays in the longest path.

The overcurrent relays can operate in two modes: the instantaneous mode and inverse-time mode. The overcurrent relay model, as stated in IEC 60755-4 characteristic, is given as:

$$T = \frac{K_1 \times TDS}{\left(M^{K_2} - 1\right)} \qquad (2)$$

where T is the operating time, M is the multiplier of pickup current (I_f/I_p), K_1 and K_2 are relay constants defining the characteristic of the relay, TDS is time dial settings.

The objective function has to satisfy the following constraints:

1- Coordination criteria

$$T_{i-1,j} - T_{i,j} \geq \Delta t \qquad (3)$$

where the time Ti-1,j is the operating time of the primary relay, Ti,j is the operating time of the pickup relay and Δt is coordination time interval (CTI). It is common to take the value of Δt as: $\Delta t \approx 0.2$ second.

2- Bounds on the relay settings

$$TDS\ min \leq TDS \leq TDS\ max \qquad (4)$$

$$Ip\ min \leq IP\ i \leq Ip\ max \qquad (5)$$

where Ip is the pickup or trip current. Usually the time dial setting of relay can start from values as low as 0.1 second and as high as 20 second. Typical limits of TDS are as follows:

$$0.1 \leq TDS \leq 20 \qquad (6)$$

3- Relay Model

$$T = \frac{k_1 \times TDS}{\left(\left(\frac{I_f}{I}\right)^{k_2} - 1\right)} \qquad (7)$$

The variable M can be defined as follows:

$$M = \frac{I_f}{I} \qquad (8)$$

$$T = a \times TDS \qquad (9)$$

$$J = \sum_{i=1}^{n} a_i \times TDS_i \qquad (10)$$

where "a" is a function of (M) as indicated by the following equation:

$$a = \frac{k_1}{M^{k_2} - 1} \qquad (11)$$

TDS_i values are determined by minimizing objective function (J) and achieving the related constraints.

III. Case Study

In the last five years, many gas-turbine power plants are installed in Egypt such as Damietta (4×125 MW), El Shabab (8×125MW) and 6 October (500MW). The internal networks used to supply the auxiliaries of all these plants are almost the same. Fig. 1 describes the medium voltage switchgear for this internal network.

Fig. 2 describes the low voltage switchgear for this internal network. Every two turbines have medium voltage switchgear of two sections to supply their auxiliaries. Thus, power plants will have one medium voltage switchgear for each two turbines. In case of using four turbines, two medium voltage switchgears will be used. Finally, additional one-medium voltage switchgear will be used to energize the common auxiliaries in case of whole plant black start, where a diesel generator will be connected to this medium voltage switchgear. Due to this complex construction, many operation scenarios can be proposed.

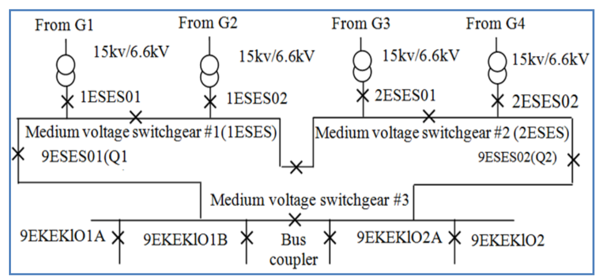

Fig. 1a) The single-line-diagram

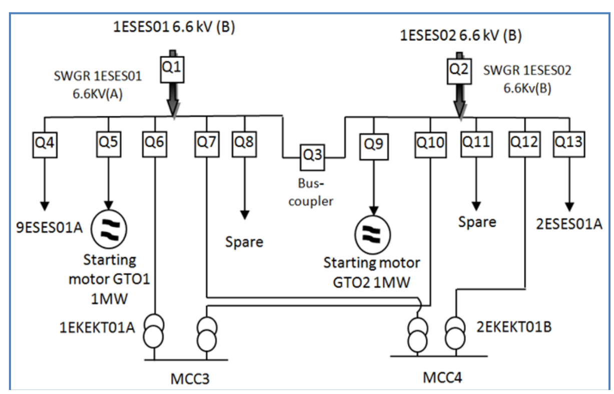

Fig. 1b) Details of switchgear #1 (1ESES01)

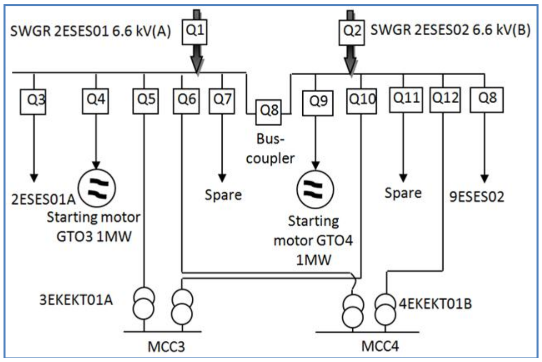

Fig. 1c) Details of switchgear #2 (2ESES01)

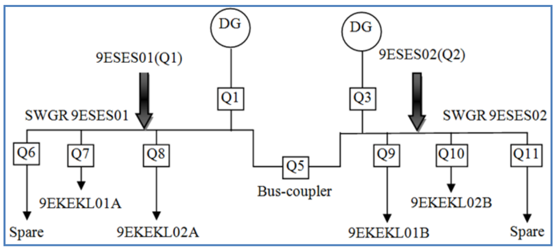

Fig. 1d) Details of switchgear #3 (9ESES`)
Fig. 1, Configuration of the medium-voltage switchgears

These scenarios are designated according to the number of auxiliary transformers in service and the status of bus couplers or bus ties between switchgears (i.e. close or open). Overcurrent protection is used as the main protection for this medium voltage networks and its low voltage networks. Bidirectional load flow within this network will limit the usage of directional overcurrent protection. To help in solving this problem of coordination, this paper presents a complete solution for this type of problems based on the multi-group feature in digital relay. More explanation for the proposed method will be introduced in the following section.

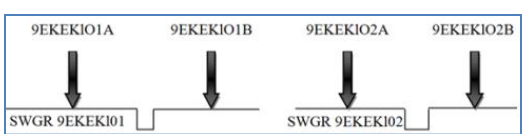

Fig. 2a) Connection of low voltage switchgears

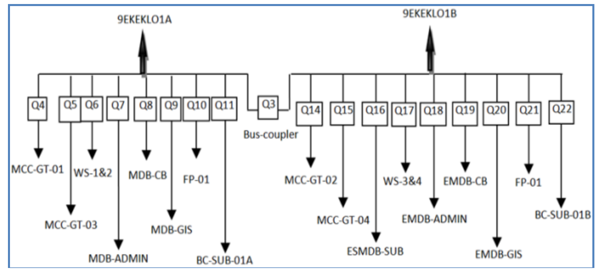

Fig. 2b) SLD of switchgear (9EKEKL01)

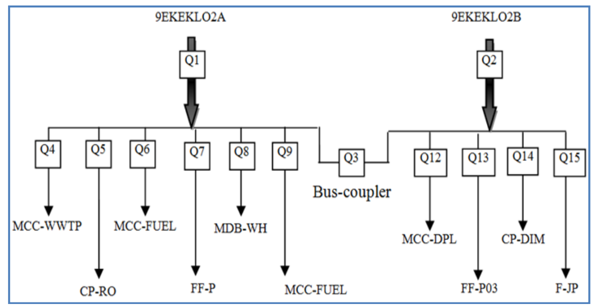

Fig. 2c) SLD of switchgear (9EKEKL02)
Fig. 2, Configuration of low voltage switchgears

IV. Proposed Algorithm

The steps of the proposed method is illustrated in Fig. 3. The main steps are to generate primary and backup pairs of OC relays and perform load flow and fault studies. Then, initial settings are checked by ETAP before using the optimizing methods. LP is used as a deterministic method to obtain the optimal values of TDS values that meet the constraints of operation and achieve the minimum operating time of OC relays.

4.1 Overcurrent relays coordination in low voltage area using conventional methods

The following basics are taken into consideration regarding the operation of low voltage switchgears:

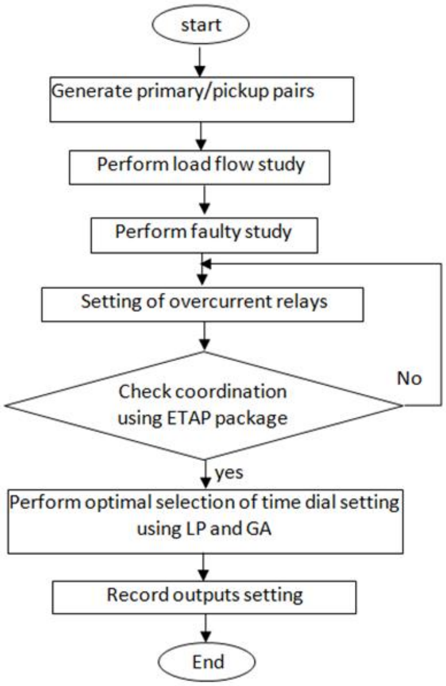

Fig. 3, Flowchart of the proposed method

- The pickup current and trip time of loads fed from load centers are set based on the rated current and cable data sheet shown on the single line diagram of load center.
- Thermal setting for the protective devices will be within the range of (1.1-1.25) of the full load current and does not exceed the outgoing cable ampacity.
- Magnetic setting for the protective devices will be 10 times the nominal full-load current
- Medium voltage "MV" cables damage curves are IEC 60502 Standard and are based on temperature ratings listed in cable data sheets as follows: normal temperature is 90 ^{o}C, emergency temperature is 130 ^{o}C and short circuit temperature is 250 ^{o}C.
- The settings for all OC relays of incoming feeders are based also on load rated current and cable data sheet shown in the single line diagram.
- ETAP software is used to verify the coordination setting.

4.2 Normal operation scenario

This scenario is achieved when all 4 auxiliary transformers are in service and bus ties between switchgear sections are open. According to this scenario, the network is specified as a radial network. Fig. 4 shows the coordination between the bus coupler relay (1ESES0103) and its outgoing relays that operate during this mode.

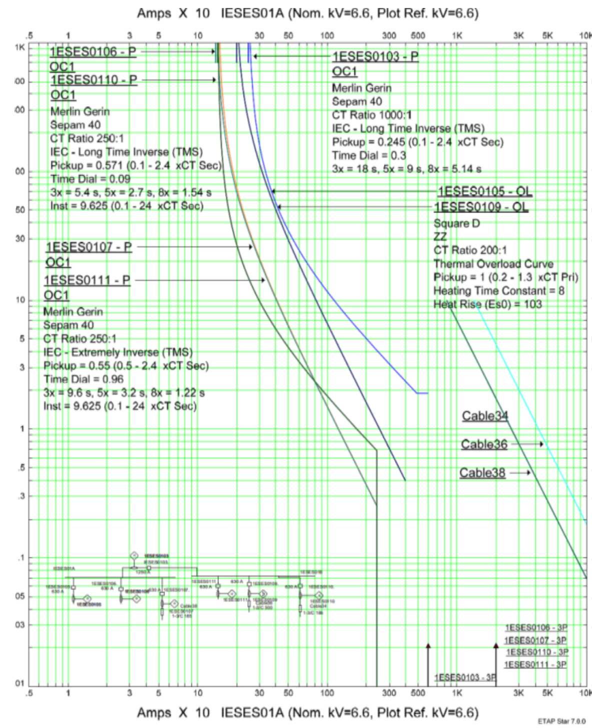

Fig. 4, Coordination between the bus coupler relay (1ESES0103) and its outgoing relays

Fig. 5 highlights the coordination between the MV incoming relay and out-coming relay with the thermal damage cable.

Finally Fig. 6 illustrate the coordination among MV 9ESES01, LV relay 9EKEKL02 and thermal damage cable of transformer. The coordination is examined using the ETAP software and many trials are carried out to ensure that the total clearing time at the common MV switchgear bus is minimized.

The clearing time will change for other operating scenarios. To show that the power flow in the network may change its direction due to the operating mode, the case when only one auxiliary transformer is in service, while the other three auxiliary transformers are out of service, is taken into consideration. Among the available four cases in this mode, two cases represent the worst operating condition.

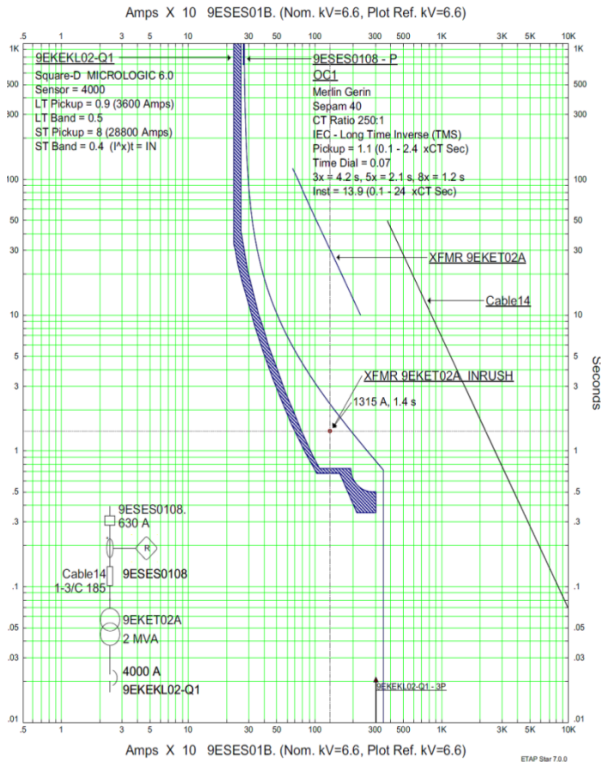

Fig. 5, Coordination between the MV incoming relay and out-coming relay with the thermal damage cable

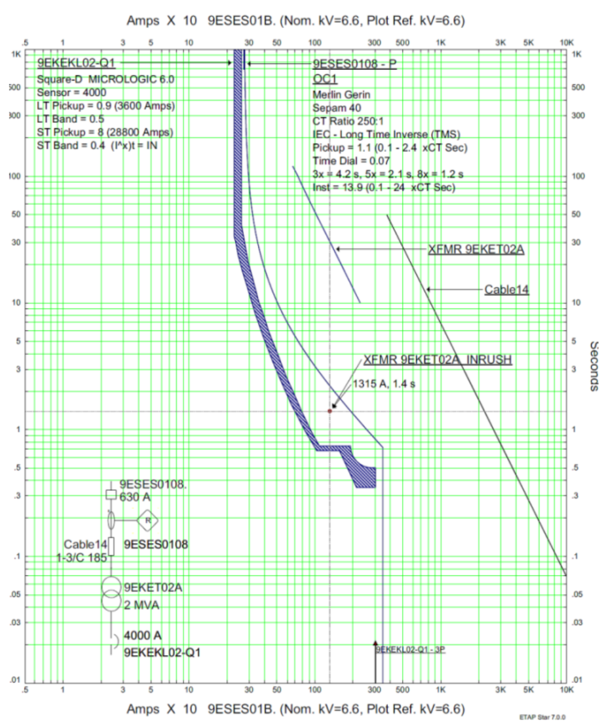

Fig. 6, The coordination among MV 9ESES01and LV relay 9EKEKL02 and thermal damage cable of transformer

From the protection coordination point of view, these two cases are when the first, or the fourth, auxiliary transformer is in serve alone without the other three auxiliary transformer. Considering these two cases the following points will take place.

1- Total clearing time for faults in the incoming feeder of unit MW switchgear will be affected.

2- Due to the reverse of power flow in the two cases, each case will have a sequence of coordination not suitable for electromagnetic relays.

To overcome the problem stated above in point 2, multi-group feature in digital relays has to be used. Digital relays contain a multi-group setting feature, but only one group can be selected at any time according to the status of network. Under some conditions, the number of groups in digital relays may change according to manufacturer. However, at least two groups are available for most of digital relays produced nowadays. Thus, the proposed technique depends on using only two groups to solve problem mentioned above.

The first group will cover the condition of operation when the first auxiliary transformer is in service. On the other hand, the second group will cover the condition when the fourth auxiliary transformer is in service. Fig. 7 shows the coordination curves for the first case.

4.3 Black start scenario

In Black start, a diesel generator is connected to the common MV switchgear to provide the required power. Hence, the diesel generator has to be capable of supplying all loads during emergency situations such as shut down and black start.

This scenario will illustrate the change in coordination due to the reverse power in the network. Digital relays contain a multi-group setting feature, but only one group can be selected at a time according to the status of network and the direction of power flow. The concept of solving the problem using the multi-group feature will be applied once again for these new relays. Fig. 8 through Fig. 10 show the coordination curves for the relays considering this scenario.

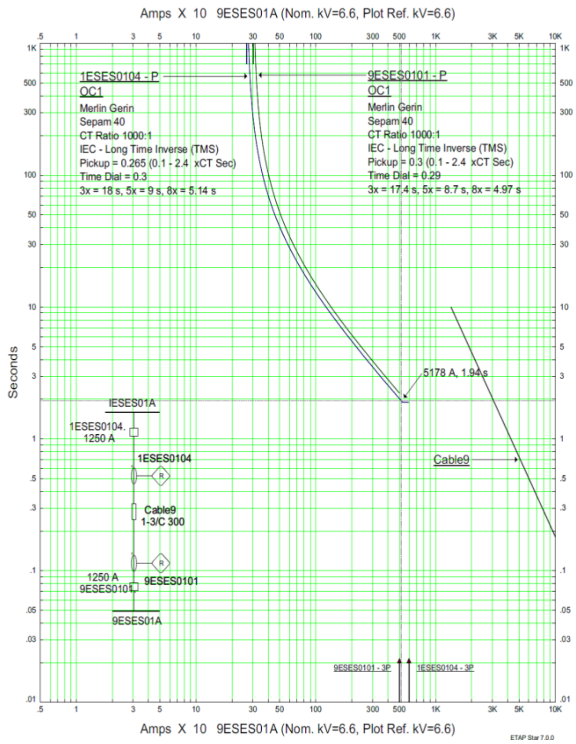

Fig. 7, Coordination curves when first auxiliary transformer is in services

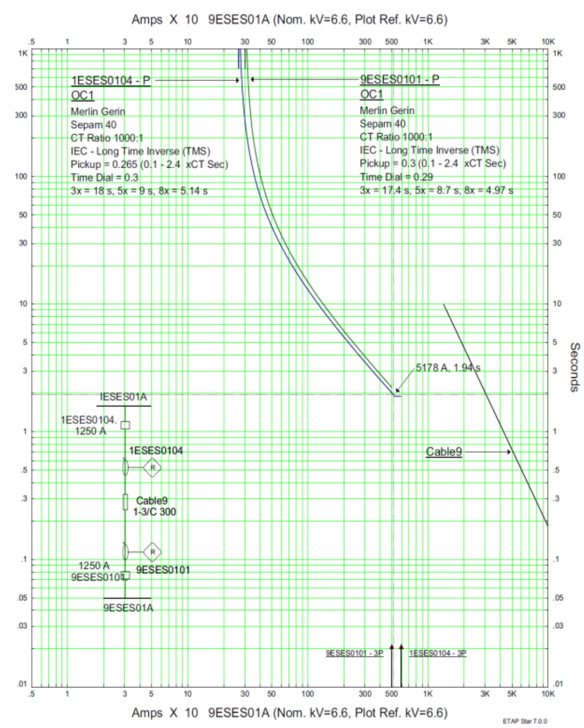

Fig. 8, The coordination among MV 9ESES01and incomers relay in black start mode

4.4 Investigating Overcurrent relay coordination for MV switchgears

To implement the proposed coordination study for MV switchgear, there are some setting criteria that must be considered:

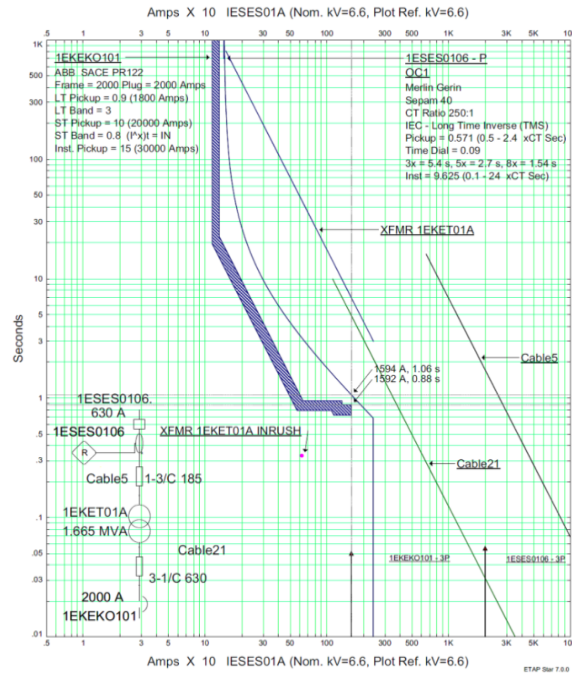

Fig. 9, The transformer inrush current and the coordination curves between 1ESES01, the incoming breaker of 1MCC-TR, and the cable and transformer thermal damage curves.

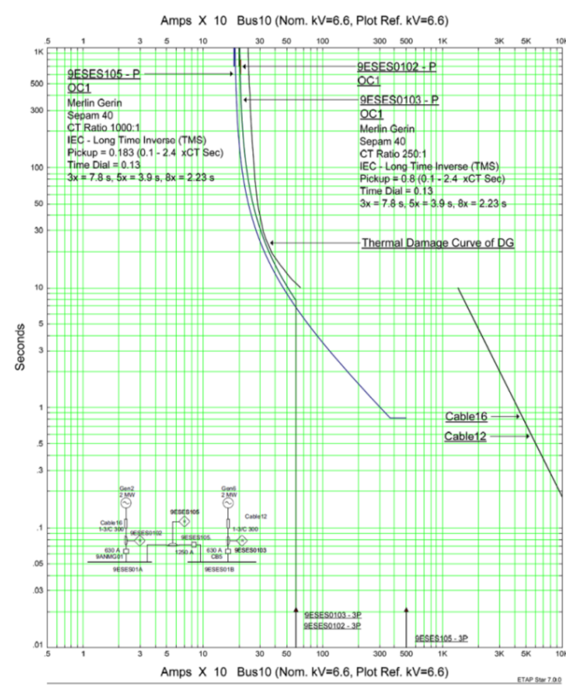

Fig10 The coordination curve among 9ESES01 and the diesel generator circuit breaker and the thermal damage curves of transformer, generator and cables

- The secondary neutral of the auxiliary transformer is grounded through (6.3 ohm reactor, 600 A, 30sec) according to the standards of the Egyptian ministry of electricity.
- The maximum 3-phase short circuit current is defined according to IEC 6050 standard and based on temperature ratings listed in cable data sheets. The normal temperature is 90 ^{o}C, emergency temperature is 130 ^{o}C and short circuit temperature is 250 ^{o}C
- The neutral point of each diesel generator is grounded through (9.5 ohm resistance, 100A, 30sec).

V. Optimization Of Overcurrent Relay Coordination

Optimization techniques are used to obtain the optimal solution of overcurrent relay coordination problem. According to the proposed method, the initial setting of OC relays are accomplished by conventional methods and then the settings are optimized by the LP and GA methods. The results obtained by LP and GA are compared in Table [1]. The results are identical but they are different from those obtained using conventional method.

Table 1 The results of time delay setting (TDS) using conventional and optimization methods

TDS	By conventional method	By linear programming	By Genetic Algorithm
TDS1	0.1	0.1	0.1
TDS2	0.3	1.0229	1.0229
TDS3	0.571	0.5747	0.5747
TDS4	0.3	0.5779	0.5779
TDS5	0.183	0.1382	0.1382
TDS6	0.7	0.1268	0.1268
TDS7	0.5	0.1	0.1

Fig (11) shows the path of overcurrent relays to be coordinated in case of only one auxiliary transformer is in service, while the values of TDS of OC are given in Table [1] for conventional and optimization methods. Numbers, from 1 up to 7, are assigned to the TDS for each relay as shown in Fig. 11.

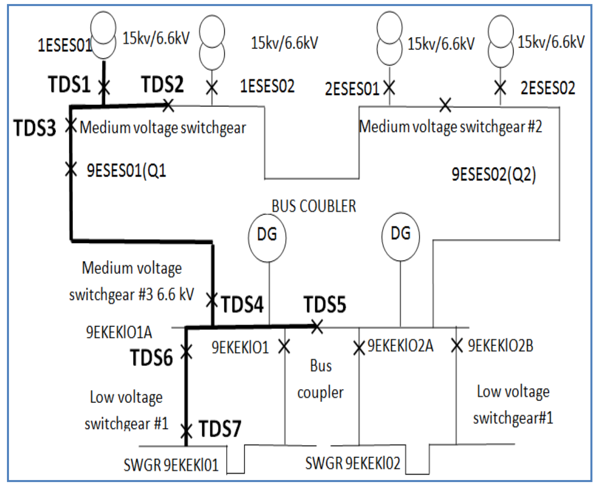

Fig. 11, The path of overcurrent relays to be coordinated in case of only one auxiliary transformer in service

Fig. 12-a shows the coordination curve between the relay 9ESES0101 and the relay 1ESES0104 with the thermal damage curve for the cable using convebtional method. According to this coordination, the optimal values of TDS achieve the main objective function, that gives the minimum clearing time. Fig. 12-b, shows the coordination between the MV relay 9ESES01 and LV load center 9EKEKL01-A and its transformer thermal damage curve.

Figs. (13-a, b) present the coordination curves using linear programming. Fig13-a indicate the coordination curve between the relay 9ESES0101 and the relay 1ESES0104 with the thermal damage curve for the cable. On the other hand, Fig13-b shows the coordination between the MV relay (9ESES01) and LV load center relay 9EKEKL01-A and its transformer thermal damage curve.

Fig. (14-a, b) shows the coordination curves using GA. Fig14-a indicates the coordination curve between the relay 9ESES0101 and the relay 1ESES0104 with the thermal damage curve for the cable. Also, Fig14-b shows the coordination between the MV relay (9ESES01) and LV load center 9EKEKL01-A and its transformer thermal damage.

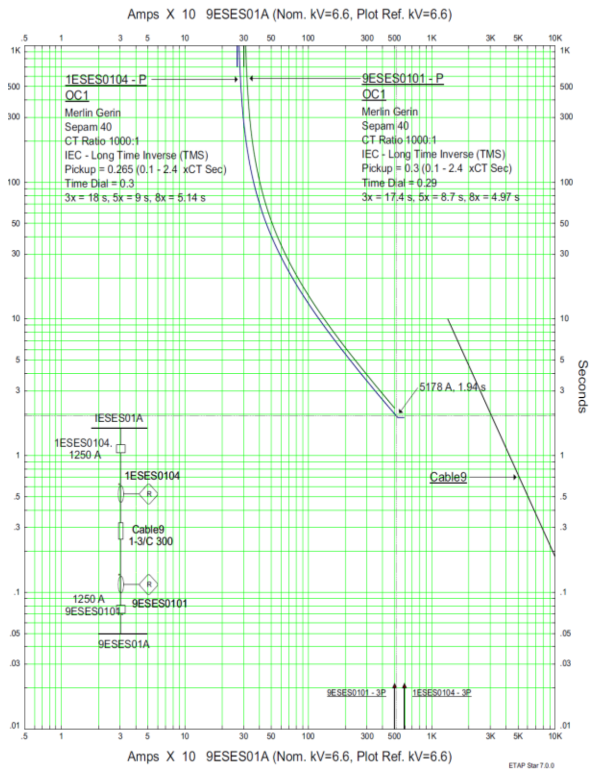

Fig. 12-a, The coordination curve between the relay 9ESES0101 and the relay 1ESES0104 with the thermal damage curve for the cable by conventional method

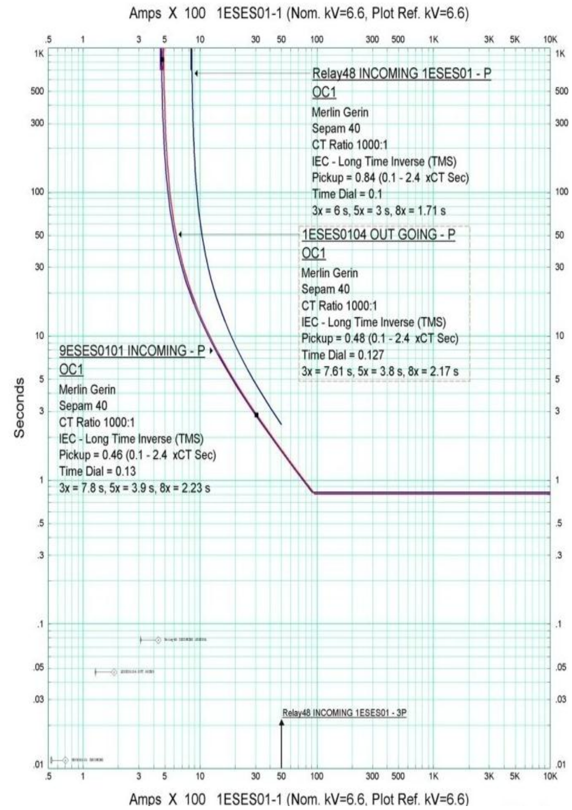

Fig. 13-a, The coordination curve between the relay 9ESES0101 and the relay 1ESES0104 with the thermal damage curve for the cable by using linear programming

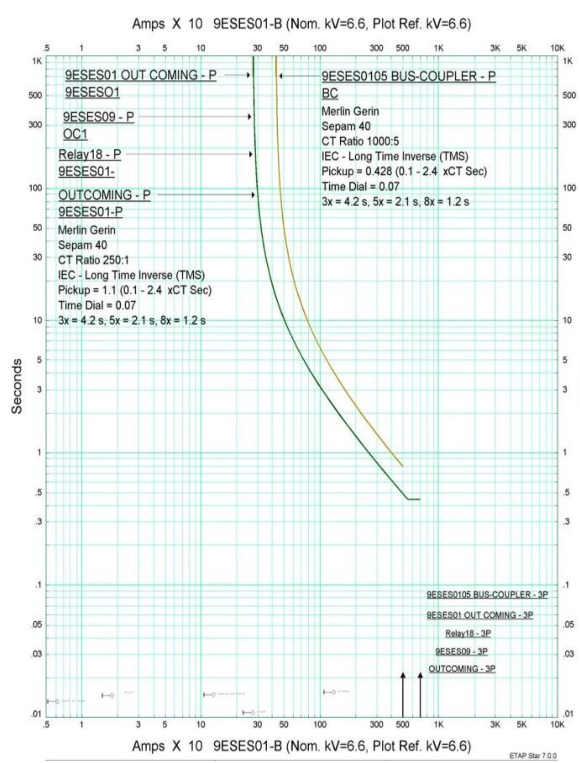

Fig. 12-b, The coordination between the MV relay (9ESES01) and LV relay 9EKEKL01-A and its transformer thermal damage curve by conventional method

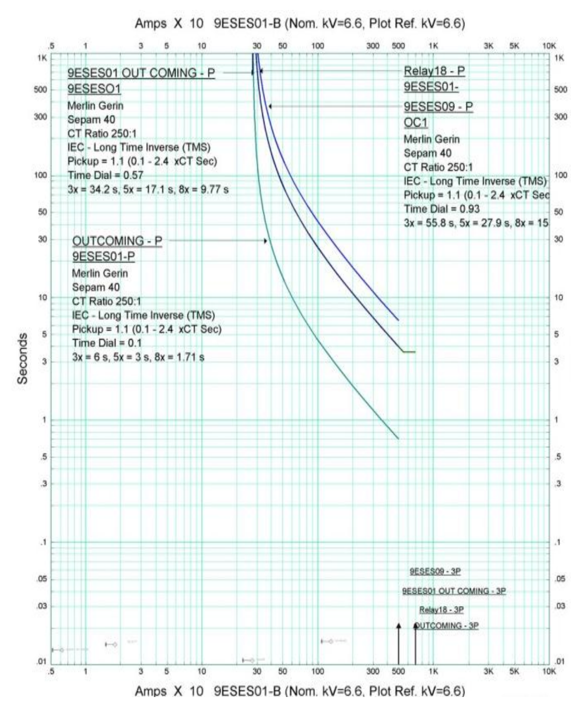

Fig. 13-b, The coordination between the MV relay (9ESES01) and LV relay 9EKEKL01-A and its transformer thermal damage curve by using LP

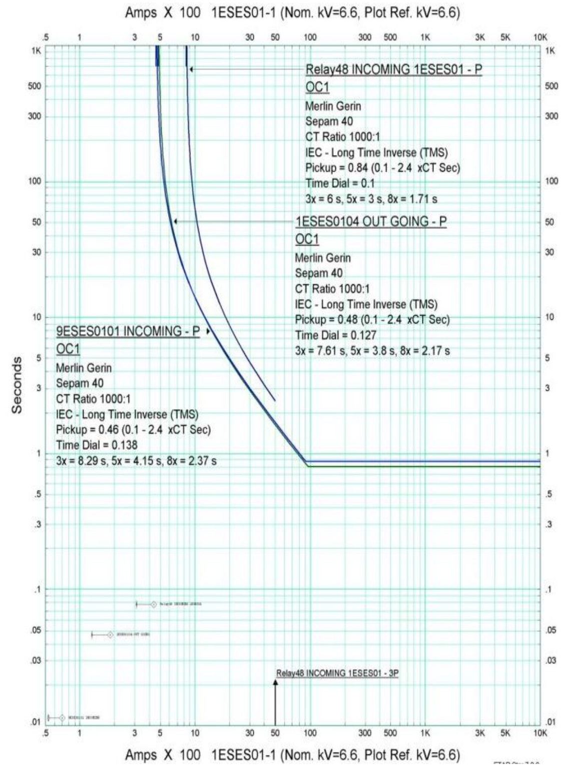

Fig. 14-a The coordination curve between the relay 9ESES0101 and the relay 1ESES0104 with the thermal damage curve for the cable by using GA

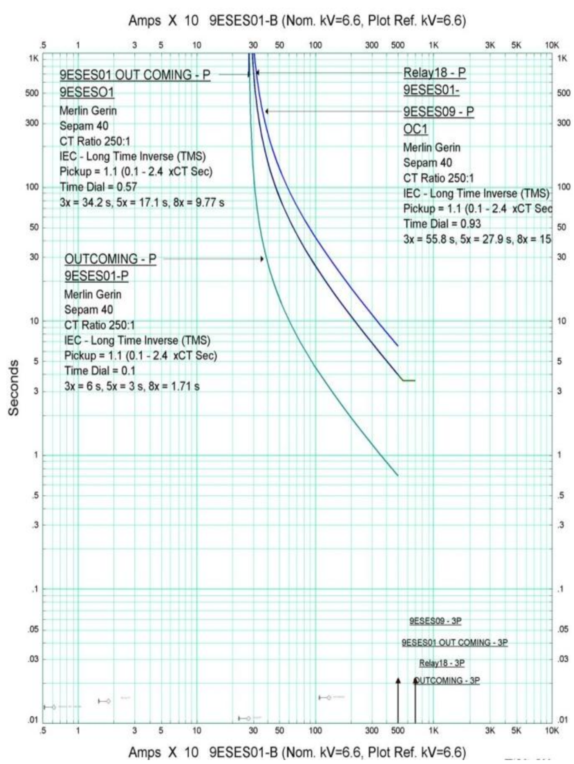

Fig. 14-b The coordination between the MV relay (9ESES01) and LV relay 9EKEKL01-A and its transformer thermal damage curve by using GA

VI. Conclusion

The coordination problem of overcurrent relays is defined and solved using onventional and artificial intelligent techniques. This is performed to obtain the optimal setting values of TDS for each relay in Damietta, Egypt, power plant. The modes of operation as well as the topology of the network are taking into consideration. The expert rules and IEC codes are used to set the OC relays, which represent an initial solution followed by applying optimization techniques to obtain the fine and optimal solution. The ETAP software is also employed to check and reset the setting parameters of relays to establish an initial and efficient solution of coordination of OC relays. The optimal TDS values achieved the required minimum clearing time, which is illustrated by examiming many coordination curves using ETAP for different TDS values. GA and LP show high capability to solve the coordination problem and provide better results compared to conventional methods.

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