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Design and Implementation of an over Current Protection Laboratory for Electrical Power Transmission Systems Based on PLC Techniques

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Abstract

This paper describes a modern approach for the protection of transmission lines to ensure their safety against the faults occurred in power systems. Our approach uses a_Programmable Logic Controller (PLC) to realize a transmission line as an over current protection relay. A conditioning circuit was designed, implemented and tested to collect data obtained from Hall Effect sensors which convert them to suitable analog values compatible with PLC's inputs. Results obtained by our PLC control system are very similar to those obtained by the conventional relays but more efficient. An Automatic Reclosing System (ARS) for remote faults is also included in this approach. Our PLC control system and its algorithm are illustrated in this paper also. This approach is designed to be used in electrical networks laboratories as an educational unit in electrical departments of engineering collages and technical institutes; it can be used also in real power systems through suitable interfacing facilities.

Keywords: PLC, over current protection, hall effect sensors.

تصميم وتنفيذ مختبر لحماية أنظمة نقل الطاقة الكهربائية من التيارات المتجاوزة باستخدام تقنيات المتحكمات المنطقية القابلة للبرمجة

الخلاصة

يقوم هذا البحث بتصميم وتنفيذ أسلوب حديث لحماية خطوط نقل القدرة الكهربائية من أخطار الأخطاء الكهربائية التي تحدث في أنظمة القدرة الكهربائية. تم استخدام المتحكم المنطقي القابل للبرمجة بدلا من مرحّل تجاوز التيار الكهربائي التقليدي لحماية خط نقل القدرة الكهربائية، وذلك عن طريق تصميم وتنفيذ وفحص نظام مبرمج لجمع المعلومات المطلوبة عن طريق متحسسات تأثير هول التي تقوم بتحويل قيم التيار المقاسة من خط نقل القدرة الكهربائية الى قيم تناظرية متوافقة مع إدخالات المتحكم المنطقي القابل للبرمجة، ثمّ يقوم المتحكم المنطقي بمقارنة القيم التناظرية التي تمّ الحصول عليها بالقيمة المرجعية لتيار الفصل المثبتة في خوارزمية المتحكم المنطقي. لقد كانت النتائج التي تمّ الحصول عليها باستخدام هذا النظام متشابهة جدا مع تلك التي يتمّ الحصول عليها عادة في المختبر في حالة استخدام مرحّل تجاوز التيار الكهربائي التقليدي ولكن بصورة أكثر كفاءة. يمكن لهذه الخوارزمية أيضا تنفيذ نظام إعادة الغلق لقواطع الدورة الكهربائية عند حدوث الأعطال في الأماكن النائية مع إمكانية إطلاق إشارة تنبيه عند عدم زوال العطل. لقد تمّ تصميم هذا النظام كوسيلة تعليمية في مختبرات الشبكات الكهربائية في أقسام الهندسة الكهربائية لكليات الهندسة والمعاهد التقنية، كما يمكن استخدام هذه الوحدة في أنظمة نقل القدرة الكهربائية الحقيقية باستخدام وسائل تحسس وربط مناسبة.

الكلمات الدالة: المتحكمات المنطقية القابلة للبرمجة، حماية تجاوز التيار، متحسسات تأثير هول.

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Introduction

Recently, the trend in power and control protection systems is to implement the programmable protection systems that can easily interface with transducers from one side and the dispatch control center from the other side[1]. This research attempts to design and implement an over current protection unit using a programmable logic controller (PLC) to replace the classical protection relay. The PLC (The Brain) will cause the circuit breaker to trip when the load current reaches the setting value in the PLC as shown in Figure (1).

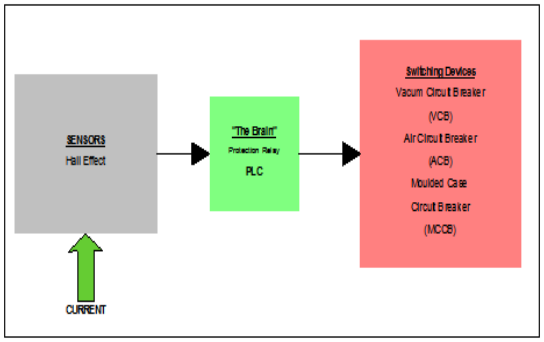

Fig. 1. Building block of protection system

Due to its advantages as, low cost, easy installation and programming [1,2], the usage of PLC was investigated in this paper to provide over current protection in power transmission lines. Logic relations and related control rules are realized through a developed PLC program. The PLC system hardware includes, in addition to its standard components, analog Hall Effect transducers as inputs and an operator's terminal (output), as a Human Machine Interface (HMI). Also in this paper, a simple Automatic Reclosing System (ARS) is designed and automated to protect the remote parts of the transmission line from temporary faults by isolating the faulty part of the distribution electrical network.

Over Current Protection of a Transmission Line

Over current protection is the most popular and used technique in distribution and protection systems. This technique basically depends on over current relays especially the inductive type which depends in their operation on the interaction between two magnetic fluxes φ_1, φ_2 and the induced eddy currents in the moving part of the relay [3]. The electromagnetic rotational torque T is proportional to φ_1, φ_2 and the sine of the angle between them [3]. In general,

$$T \propto \varphi_1 \varphi_2 \sin\theta \quad \ldots\ldots(1)$$

Where θ is the angle between φ_1 and φ_2 .

Torques generated in the relay are [3]:

1- Operation Torque T_1 which is proportional to square of the relay's current.

$$T_1 = K_1.I^2 \quad \ldots\ldots(2)$$

Where K_1 – Constant, I - Operating current of the relay

2- Counter Spring Torque T_2 which is constant.

$$T_2 = K_1.I'^2 \quad \ldots\ldots(3)$$

Where I' - Pickup current

3- Suppression Torque T_3 which is proportional to the speed of the relay's disc.

$$T_3 = K_2 . d/t \quad \ldots\ldots(4)$$

Where d - Distance that the disc moves till it closes its contacts, t - Time of disc's movement, K_2 - Constant

From equations 1, 2 and 3,

$$T = K_1 . I^2 - K_1.I'^2 - K_2\,(d/t) \quad \ldots\ldots(5)$$

Where T - The resultant operating torque

The disc starts rotation when T =0, or

$$K_1\,(I^2 - I'^2) = K_2\,(d/t) \quad \ldots\ldots(6)$$

Or

$$t = (K.d)/(I^2 - I'^2) \quad \ldots\ldots(7)$$

Where $K = K_2/K_1$

The relation in Equation (7) shows that for given values of (d) and (I'), the operating time (t) of the relay is inversely proportional to the square of the current (I) passing through the relay, because of that, they are known as Inverse Time Relays, as shown in Figure (2).

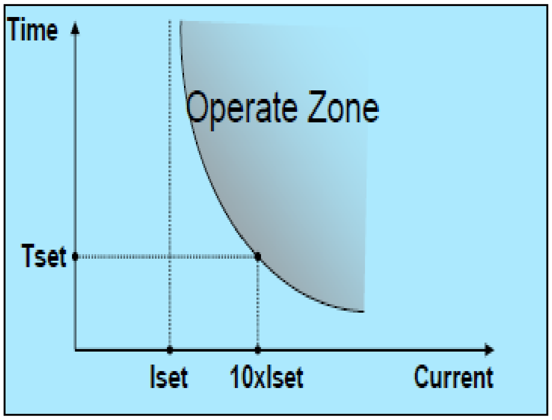

Fig. 2. Operating zone of inverse time protection

Figure (3) shows the basic internal construction of a classical electromechanical over current relay.

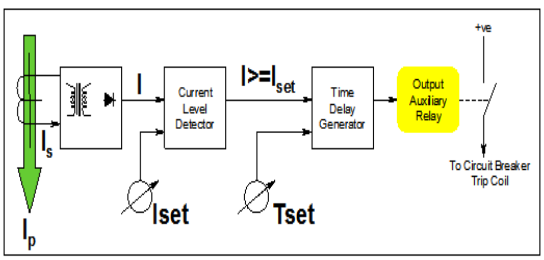

Fig. 3. Basic construction of an over current relay

Where:

I_p - CT primary current.
I_s - CT secondary current.
I - Operating current of the relay.
I_{set} - Operating current setting.
T_{set} - Time delay setting of the relay.

I_{set} and T_{set} in Figure (3) are used to determine the operating zone of the relay as shown in Figure (2). There are different inverse relations between operating time and current as shown in Figure (4), which are [4]:

1. Standard Inverse (SI).
2. Very Inverse (VI).
3. Extremely Inverse (EI).

The over current relay can be used also for Definite Time (DT) protection [4] by setting the time and current of this type of protection as in Figure (3). The characteristics and the operating zone of the DT relay are shown in Figures (4) and (5).

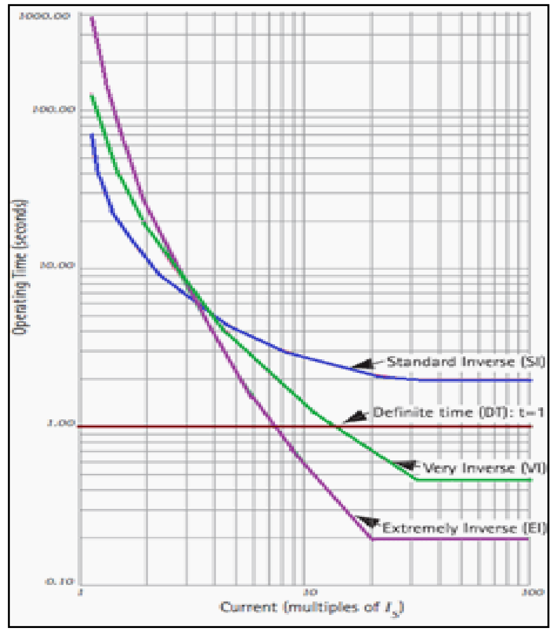

Fig. 4. Inverse Types

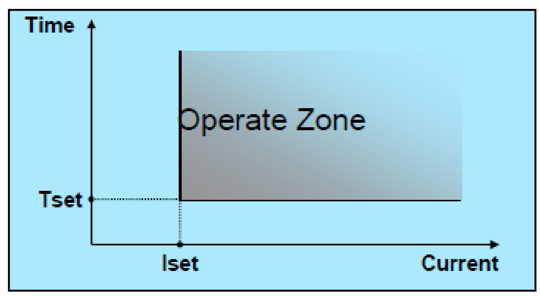

Fig. 5. Operating zone of definite time protection

PLC Implementation in Over Current Protection

Most functions and operations provided by very sophisticated and expensive over current relays can be simulated by using PLC in easier and much cheaper ways [5]. Our approach is highly appreciated and valuable for educational training in electrical networks laboratories of institutes and universities by using simple and inexpensive units.

By using PLCs in over current protection of transmission lines circuits, all the various facilities of the PLCs are transferred to these circuits [6]. This gives the protection circuits more flexibility and makes their integration with other protection and control circuits easier.

A simplified flow chart of the PLC logic program of over current protection for transmission lines is shown in Figure (6).

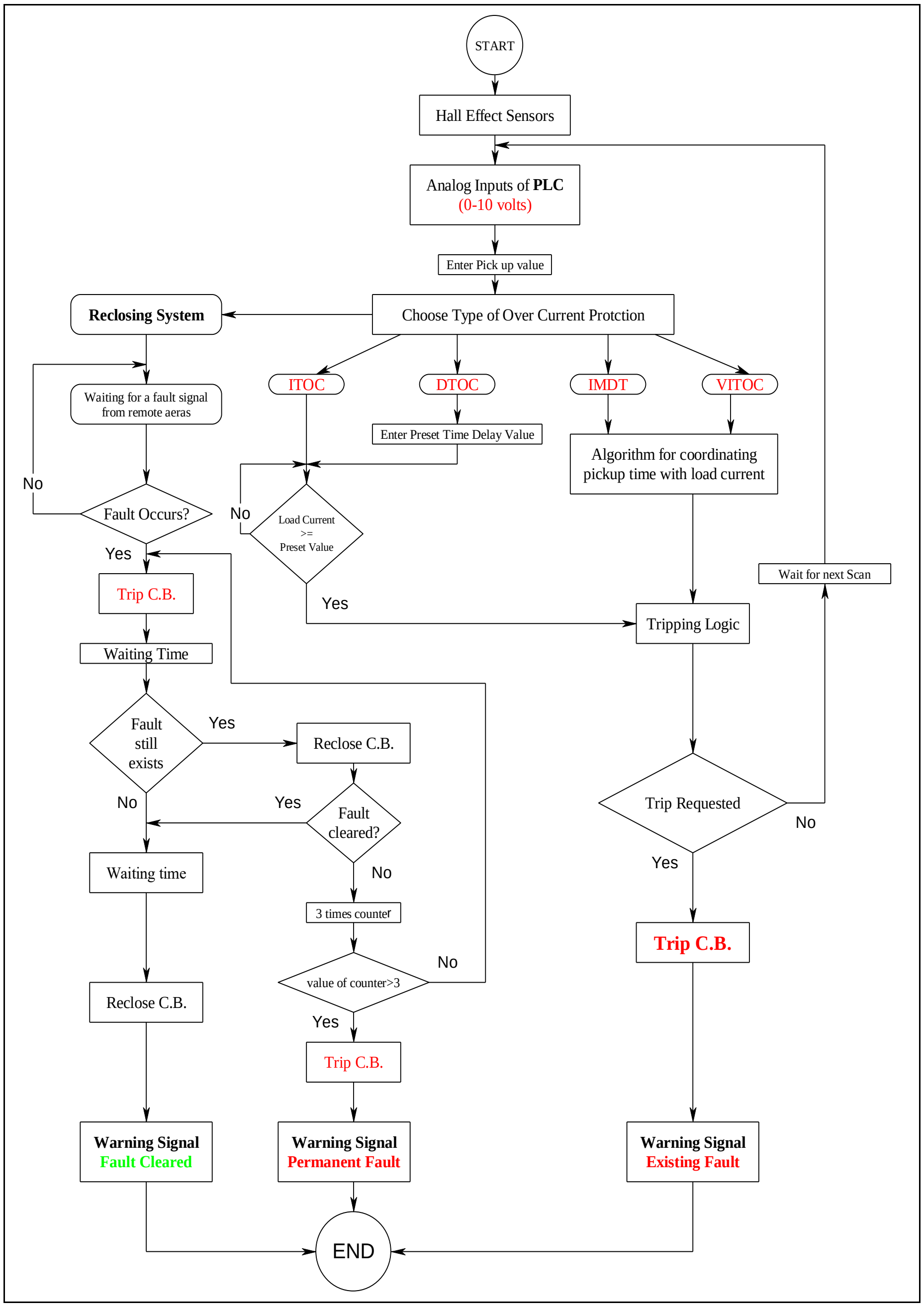

Fig. 6. A simplified flow chart of the PLC logic program

As shown in Figure (6), four types of over current protection were studied and they are:

- **Instantaneous Over Current protection (ITOC)**, which operates instantaneously (magnetic type) when the current reaches a predetermined value. The logic configuration [7] of this relay is shown in Figure (7-a) and its characteristic curve [8] is shown in Figure (7-b).

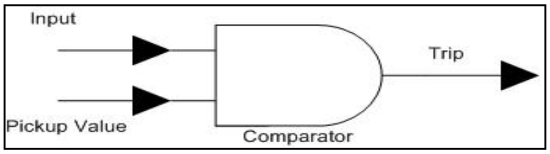

Fig. 7-a. Logic principles of instantaneous O.C. protection

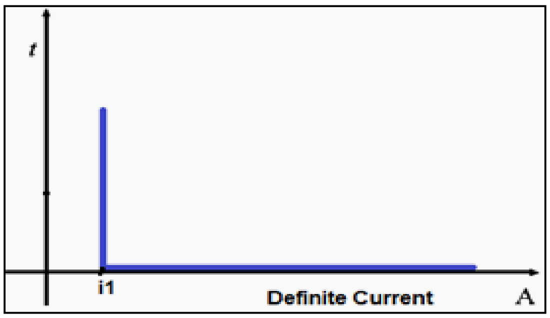

Fig. 7-b. Characteristic curve of instantaneous O.C. protection

- **Definite Time Over Current protection (DTOC)**, in this type of protection, two conditions must be satisfied for operation (tripping), current must exceed the setting value and the fault must be continuous at least a time equal to a preset time value[7]. Its characteristic curve is shown in Figures (4) and (5), many parameters are taken into account when designing the simulation algorithm such as operating time is kept constant and the operation of the system is independent of the magnitude of current above the pick-up value.
- **Inverse Minimum Definite Time over current protection (IMDT)**, in this type of protection, operating time is inversely changeable with current. So, high currents will operate the over current protection faster than lower ones [7]. Its characteristic curve is shown in Figures (2) and (4).
- **Very Inverse Time over Current protection (VITOC)**, this type of protection gives more time inverse characteristics than that of IDMT. It is used where there is a reduction in fault current, as the distance from source increases and when Fault Current is dependent on fault location [7]. Very inverse over current protection is particularly suitable if the short-circuit current drops rapidly with the distance from the substation and it is also suitable if there is a substantial reduction of fault current as the fault distance from the power source increases [8].

Figure (8) shows a schematic diagram of the designed and implemented system. This system gets use of the characteristics of Hall Effect sensors [9] which collect data (load current) from the transmission line (0 – 16 A) and convert it into an analog output voltage (0 – 10 V) which is proportional to its input current and compatible with analog inputs of PLC. An HMI [10] is used to enable the student in a laboratory or the operator in a control site to interact with the system. The PLC's outputs are electrical signals that trip the coil of the circuit breaker in case of a fault and gives alarm signals, also they control the operation of the ARS in case of temporary remote faults.

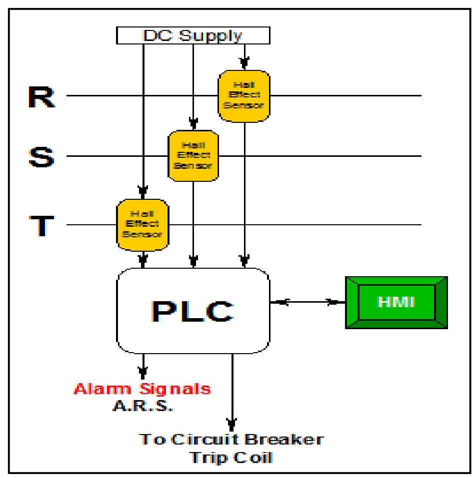

Fig. 8. Schematic diagram of the designed protection system

A section of the PLC's program is shown in Figure (9-a), this program was created using Soft Comfort V6 software of SEIMENS and implemented by LOGO! PLC V6.0 hardware of SEIMENS [10].

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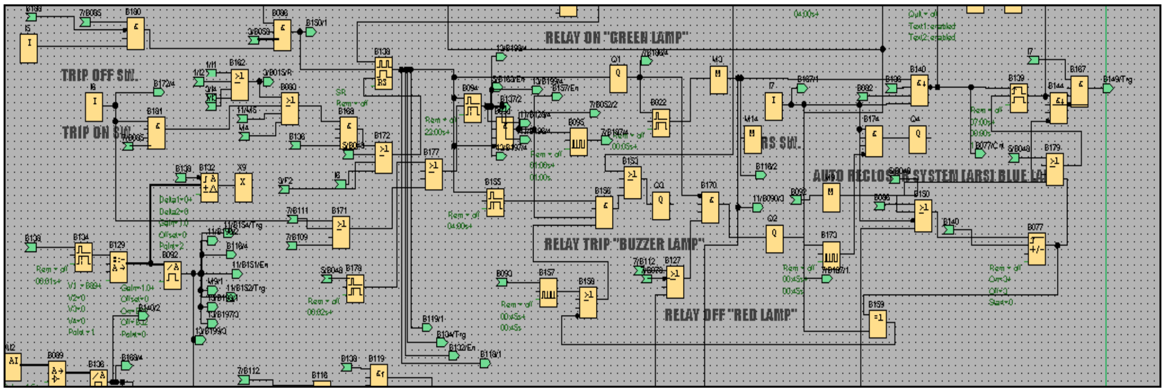

Fig. 9-a. Main program of the PLC based Over Current Relay

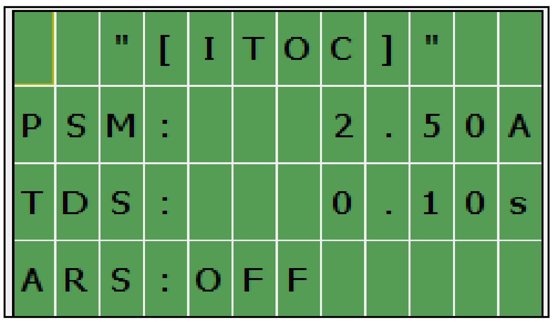

Fig. 9-b. PLC's display output of the system

A simple but efficient automatic reclosing system (ARS), which establishes a closing sequence for a circuit breaker following tripping by protective relays, is included in designing this system to monitor and protect the remote parts of the transmission line with the ability of interaction between the student or the operator and the protection system as shown in the flow chart of Figure (6).

Figure (10-a) shows the main functions of the over current protection unit which utilizes PLC techniques including:

a. Modes of over current protection.
b. HMI Unit.
c. Interactive massages for ARS mode.
d. Selective switches for over current protection modes.
e. ARS mode.

Figure (10-b) shows a close shot of the HMI which is used to establish the interaction between the operator and the protection unit such as increasing or decreasing PSM or TDS, browsing through or resetting the unit. It is also used in ARS to send confirmation signals to reset the system when the temporary remote faults are cleared.

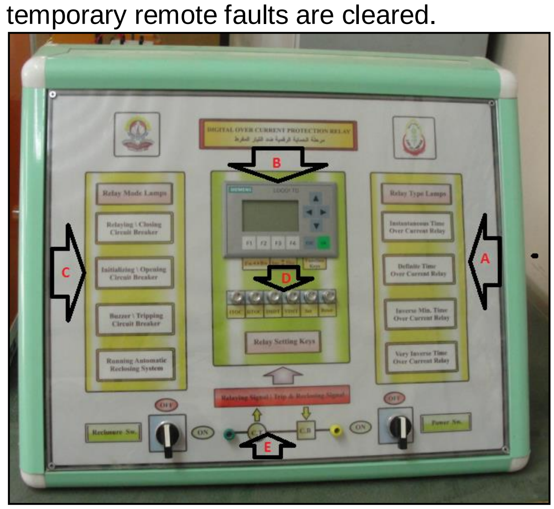

Fig. 10-a. PLC Over Current Protection Unit

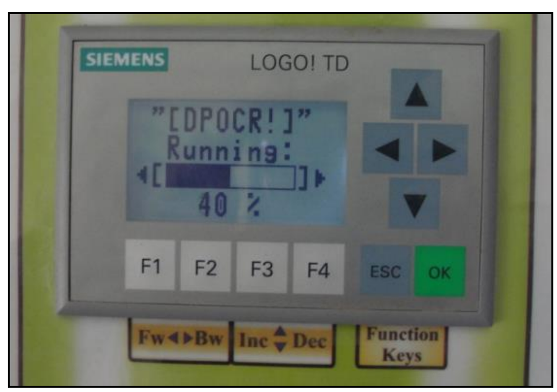

Fig. 10-b. HMI of the PLC O.C. protection unit

Figure (10-c) shows how the protection unit can be implemented to choose the type of protection by the operator who sets all the parameters by HMI.

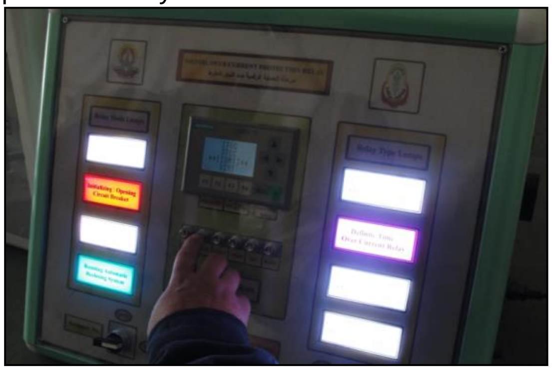

Fig. 10-c. O.C. Protection Unit in operation

Results

A comparison was established between the operation characteristics for both types of the studied over current protection relays (the classical electromechanical inductive, magnetic relays and the PLC based relay), the results of this comparison were stated as below:

1- The characteristics shown in Figure (11-a) are referred to instantaneous over current protection for both types of relays, as ideally, the relay operates as soon as the current in the relay gets higher than its pick up setting current. There is no intentional time delay applied. But there is always an inherent time delay which cannot be avoided practically. In practice; the operating time of an instantaneous relay is in the order of few milliseconds. PLC based relay is faster than traditional relay.

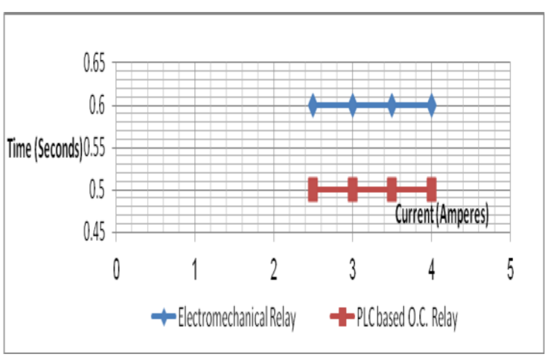

Fig. 11-a. Characteristics of Instantaneous Over Current protection (ITOC)

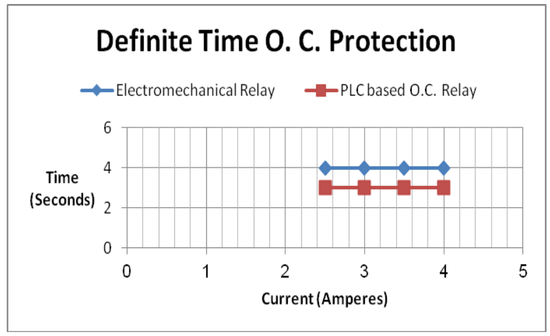

Fig. 11-b. Characteristics of Definite Time Over Current protection (DTOC)

2- A definite time over current relay can be adjusted to issue a trip output at definite amount of time after it picks up. Thus, it has a time delay and a pick up current adjustments. As shown in Figure (11-b), the characteristics of both types of over current protection are created by applying intentional time delay after crossing the pickup current.

3- Inverse time/current relation is a natural characteristic of any induction type rotating device. This means that the speed of rotation of rotating disc of the device is faster if input current is increased. In other words, time of operation inversely varies with input current. This natural characteristic of electromechanical induction disc relay is very suitable for over current protection. Although time inverse characteristic is inherent to electromechanical induction disc relay, the same characteristic was achieved and simulated in our PLC based relay by proper and efficient programming as shown in Figure (11-c).

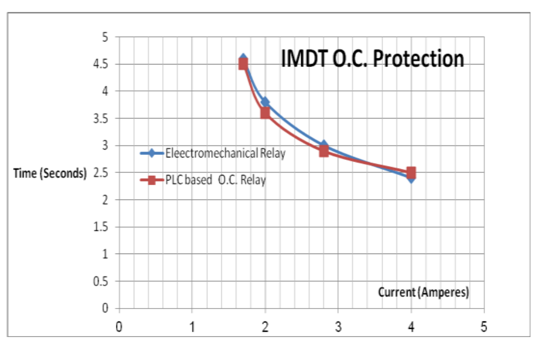

Fig. 11-c. Inverse Minimum Definite Time over current protection (IMDT)

4- Unfortunantly, the VIOC protection electromechanical induction relay isn't available in our electrical networks protection laboratory. The characteristics of these types of relays were simulated in our algorithm especially the phenomenon [7] which states that "When the CT becomes saturated; there would not be further proportional increase of CT secondary current with increased system current". Hence, the characteristic is inversely related in the initial part, which tends to a definite minimum operating time as the current becomes very high. Figure (11-d) shows the result of the simulation which is exactly the same as that of this type of the electromechanical relay even no CTs were used.

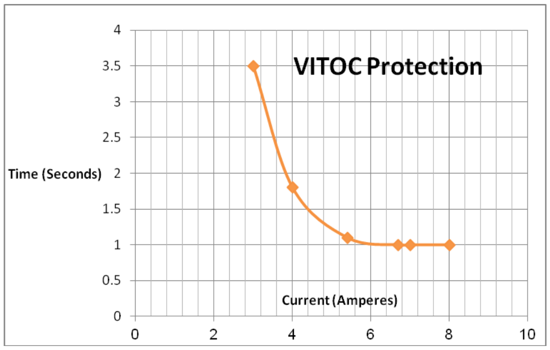

Fig. 11-d. Very Inverse Time over current protection (VITOC)

Conclusions

Using PLCs in over current protection circuits, transfers all various facilities of the PLCs to these circuits. This gives the protection circuits more flexibility and makes their integration with other protection and control circuits easier. Over current protection system model was designed to present an over current protection relay.

PLC replicates conventional approach with acceptable results. The proposed model can be used in the real power system through a suitable interfacing facility. PLC is easily controlled and programmed to obtain the desired operating characteristics. The over current protection using PLCs provides high sensitivity and stability against faults. The designed unit is found to be a very useful as an educational tool in the laboratories of the electrical departments of engineering collages and technical institutes.

Acknowledgment

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References

1. Salahat MA, Al-Zyoud AR. Modeling of transformer differential protection using programmable logic controllers. European Journal of Scientific Research 2010;41(3): 452-459.
2. Bryan LA, Bryan EA. Programmable controllers: theory and Implementation. 2nd ed. Industrial Text Company; 1997.
3. Madhava Rao TS. Power System protection: static relays. 1st ed., McGraw-Hill Publishing Co. Ltd.; 1979.
4. Gers JM, Holmes EJ. Protection of electricity distribution networks. 2nd ed., London: Institution of Electrical Engineers; 2004.
5. Hugh J. Automating manufacturing systems with PLCs; 2008. available on http://www.archive.org/details/ostengineering-plcbook5_1
6. Bolton W. Programmable logic controllers. 4th ed., Elsevier; 2006.
7. Blackburn L. Protective relaying: principles and applications. Marcel Dekker. Inc.; 2006.
8. IEEE Std. 242. IEEE recommended practice for protection and coordination-industrial and commercial power systems (Buff book); 2001.
9. http://www.cetransducer.com/Current_transducer.asp
10. 0BA6 Simatic LOGO! Manual, Siemens; 2011.