International Journal of Research in Advanced Engineering and Technology
ISSN: 2455-0876; Impact Factor: RJIF 5.44
Received: 15-06-2019; Accepted: 20-07-2019
www.newengineeringjournal.in
Volume 5; Issue 3; July 2019; Page No. 122-127

Needs to restructuring of protection systems for power electronic converters

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Abstract
Protection systems have widespread problems with expansion of power electronic equipment in size and diversity. Therefore, a short review is done on these problems and some basic requirements of a protection system are mentioned base on relay protection foundation. Then a protection block is proposed for protection of power electronic equipment.
The proposed protection scheme has independent measuring unit, calculation unit and circuit breaker. It is shown that these three parts are unqualified in current protection system for protection of power electronic equipment.
One of the main results of this paper proposal is using the solid state breakers instead of mechanical breakers. In this regard, a comparison of cost and space between mechanical and solid state breakers is done. Some special protection schemes are mentioned for power electronics at the end.

Keywords: power electronics, protection system, protection requirements

1. Introduction

Power Electronic Equipment's (PEE) have been introduced in power systems in last century and their size, diversity and applications increase every day [1, 2]. Different concepts of power systems must be rehabilitated in laws, standards, design, installations, operation and maintenance for these equipment [3, 5]. For example IEEEStd.1547 has some requirements for grid connection of DG source with and without Power Electronic Converters (PEC) but there are not any hint about protection issues of PEC [6].

Effects of PEC must be well known in custom side and especially in renewable energies for using of PEC benefits [2, 7] and some renovations must be done [6, 8, 9].

One of the most critical subjects in a power system is protection of power electronic converters. Relay and protection knowledge has long history in the electrical engineering and has had significant progress in recent years. Unfortunately protection knowledge has not been developed for PEE equal to the PEE growth. Power electronic needs new requirements in protection philosophy and protection schemes because of its special manners in operation speed, variety and faults [4, 5, 8, 10, 11].

Renewal of PEE connection is regarded from 1987 that German Association of Electric Utilities (VDEW). Also a group of IEEE has released some reports in DG effects on protection relays at 2008 that shows its serious necessity and significance [12].

Current situation of PEC connection and protection is so that the main protection is undertaken of their manufacturers. The internal control system of PEE has responsibilities of its own protection [13]. Protection of PEE is weak protections like fuse, over current and overvoltage protection according to IEEE Std.1547 at this moment. Commands of these protections are sent to Mechanical Circuit Breakers (MCB) for disconnecting. This protection has some problems and disadvantages according to mention reasons in this paper. Over current relays are insufficient for PEC is studied [14, 15, 9].

As another view, a protection system must protect both grid and equipment whereas current protection schemes protect only grid side and protection of PEE is put on their own [16].

In [17], auto-recloser and fuse operations are studied in presence of DG in distribution networks and it is shown that their coordination and operation have some problems. Also it is shown that thermal stress of auto-reclosers will increase with increase of fault current level due to PEE and overall reliability of feeder is decreased [18].

Aldo, maintenances and preventive tests must be possible periodically in a protection system but it is not practicable when the protection has been built in the equipment by their manufactures [19].

Other advantages of an independent protection system are grid automation, capability of data exchange, having SCADA [20]. But these tasks are not executable in current procedure that protections are built in PEC because manufactures do not know conditions of installation and operation of grid connection and other devices [19]. Therefore dispatching schemes and data recording systems need to independent protection system [21] as emphasized in this research. Using the proposed scheme has this facility that grid and fault data can be transferred in standard software and hardware in faulty conditions and it is independent of different manufactures software and hardware.

Some references and recommendations have a rule of thumb for PEC that they must withstand until two times of their rated current in fault conditions, but a study in [11] is shown that the current of PEC reaches until five times of rated current in a test under IEEE Std1547 and UL1741 conditions. Therefore, this rule is not sufficient for power electronic protection and it is debatable for manufacturers for their design, because it is not acceptable for manufacturers to developing of PEC with tolerable until five times of nominal current as economic view. In other hand MCB and over-current curves have long delay (relation to PEC speed) and cannot protect PEC.

As using MCB is not proper for disconnection of protection commands in presence of PEC, one offer is using Solid

State Circuit Breakers (SSCB) [14].
Also, if protection system parts be independent from other system parts then designers and owners will have some freedom degree. But there are some constrain and limitation when the control and protection are combined together [19].
In another aspect, there are some sensitive loads that they are sensitive to rapid change in network voltage like flickers and sags and MCB have not enough speed and reaction against them [13].
When some references have reached to these problems in protection system for PEC, they have gone towards the fault current limiters (FCL) [22]. They have introduced to essential usage of them. In this issue, there are two points in comparison with the proposed scheme of this paper. First, most of all CFL contain power electronics switches that they have same disadvantage as power loss and high cost. Second, the proposed schemes have this advantage in comparison with FCL that it has some flexibility for other protection like overvoltage and sensitive earth fault protections.
Some researchers have gone toward fault tolerant converter due to insufficiency of protection systems for PEC [23]. Most of these methods have comparable extra power electronic switches with the proposed method in this paper and so extra cost and extra loss.
As protection systems must have high reliability degree than controls system and more reliability needs more cost, combination of protection system and control (in a one part) cause to low reliability or high cost for both part. Therefore, the proposed method will have high reliability with lower cost for PEC. In [24] is shown that reliability issues have vital problems with 10% penetration of DG and protection system have more risk in presence of DG [25].
Another problem is contribution of PEC in fault currents. Therefore, fault will supply from two sides and coordination of protection relays will be difficult or impossible. The proposed protection block has some proper solution for these situations. Increasing short level of grid is other effects of PEC penetration in grid [11, 22, 26].
Medium voltage DC (MVDC) are grown nowadays and it seems that will more expansion in future base on their good benefits. The main issue in MVDC is that the MCB have some limitations and disadvantages in DC systems and SSCB are alone solution that it is consonant with the proposed protection block [27].
These problems are created because of that PEE have grown in size, variety and application from low to high and from customer side to grid side and from consumption side to generation side slowly until today. Therefore, their requirements are not considered seriously. One reason is that special protections are considered for high power reactive compensators is last decades [28] That those protection schemes are near to this paper proposed protection block. Consideration of basic requirements of protections system for PEE is essential today as their participation in generation, transmission, distribution and consumption in huge quantities.
At the first, philosophy and main parts of protection system is reminded in this paper. Then requirements of PEE in measuring unit, calculation unit and breaker unit are introduced base on foundation of relay protection. Next a protection block is proposed base on mentioned problem of current protection system for PEE and their requirements. Some preliminary issues like cost and space of the proposed method is compared with conventional systems.
Few new and special protection functions for PEE are proposed and some SSCB schemes are brought at the end.

2. Protection System

Protection system duty is monitoring the power system to guarantee extreme continuity of electrical supply with smallest damage equipment and properties continuously [29, 32]. Main specifications of a protection system are sensitivity, selectivity, stability, and speed [26]. Also a consistent protection system have good balancing between dependability (disconnect in the case of fault detection) and security (no operation in the case of normal condition) that they must be regular by user [34, 29, 32].
Some protection zones are defined for a protection system which the protection system of each zine operates for the only fault inside its own area. As one of the protection rule, each part of power system must be included at least one protection zone and the protections zones must have intersection with each other [29, 32].
Usually a protection system contains three parts: process unit, measuring unit, and interruption unit as shown in Figure (1) [34, 29, 32].

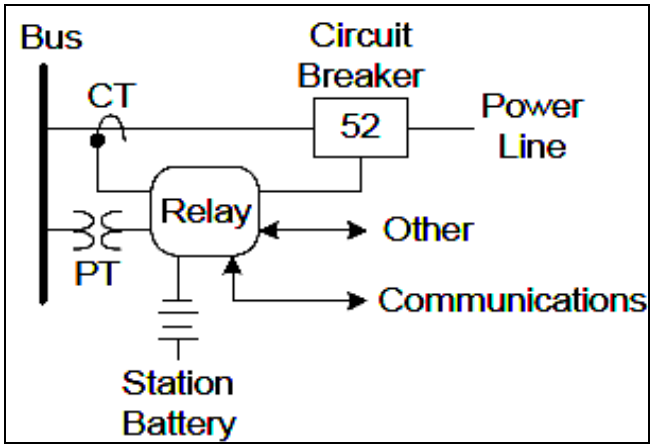

Fig 1: Main parts of a protection system

Therefore, it is unacceptable using same measuring units (CT & PT) and sensors for protection and control propose [29, 32]. Also one processing unit cannot be used for both protection system and control unit [29, 32]. A protection system needs to have different outputs like trips, alarms, and interlocking signals which they are totally different from control unit outputs [29, 32]. There are many reasons for persisting of protection part independency from other system parts. As an example, protection system measuring units must capable to measuring high value of currents and voltages in faulty condition (high currents or high voltages) with enough accuracy in faulty condition but measuring equipment (like volt meter) in the control system must have high accuracy in nominal condition. For this reason current transformer must measure current until ten times of rated value in a protection system [35]. Accuracy need is five percentages for protection system and 0.5 percentages is for control system [29, 32]. Also, disconnection part must be independent from control part in PEE. There is not access to power electronic switches in a PEE like variable speed drive [29, 32]. Because of these reasons, Methods that use common parts can be named fault detection or supervision methods not protection scheme. Therefore, the first requirement is

introduced for emphasis on protection philosophy.

(Req-1) A protection system must have independent parts and its own in measurement, processing and disconnection

Therefore, using internal signal of control system in a PEE and sending commands to power electronics switches of a PEE for protection propose must put out of the mind. A PEE must consider as a black box for protection proposes [21].

Although some supervision and fault detection algorithms have been provided by manufactures inside the PEC but they cannot consider operation and grid situations and PEC need a protection system at outside for many propose like interlocking. It can be compared with protection system of a generator in a power plant, although the generator has many protections inside from its own manufacture but a protection system is designed and developed for it with independent CT & PT and MCB.

a) ***Measuring Unit***

Most of measuring units consist of conventional CT and PT that they measure currents and voltages. They have some requirements as [35]. For example IEC255 and IEC60044-7 have considered up to 100 times of nominal current for current measurement in protection systems [19].

Unfortunately current measurement units are not suitable for PEE protection systems. The main reason is low frequency response of them. Conventional CT & PT are designed for 50Hz but PEEs have switching and nonlinear manners. Therefore, (Req-2) must be considered for these parts.

(Req-2) Measuring units for PEE protection system must have sufficient frequency band width.

It must be considered that there are wide spread spectrum of frequencies from DC to multi kilo hertz in PEE because of switching frequencies, fault frequency and their modulation. PEC have fast response because of their controllers and natural structures and they are usually connected to DC sources with high short circuit current, therefore they need to a measuring unit with minimum delay. This delay must be definable for different converters and conditions.

(Req-3) Measuring units for PEE protection system must have a maximum acceptable and settable delay.

Other specifications of measuring units can be improved according to IEEE Std. C37.110 and IEC680.

As a recommendation Hall Effect sensor and optical technologies have better performance [36, 37]. Fortunately, PEE always is installed in low voltage relative to other parts and this condition decrease cost and some technical problems.

b) ***Processing Unit***

Processing unit must do only protection task. There are some requirements for processing unit in IEEE Std. C.37.90. Also processing unit must have enough speed for fault analyzing and reaction fast proper to PEE speed. For a PEE with 2 kHz switching frequency, processing unit must do all calculation less than 50 micro seconds.

(Req-4) Processing unit for PEE protection system must be fast for signal processing and decision making proper to power electronic specifications.

Obviously (Req-4) depends on many parameters like protection function, kind of PEE, kind of switches (gate turning off switches or natural commutation switches).

As PEE are intelligent today, processing unit must be also intelligent and must have capability of using new intelligent algorithms like Neural Network (NN), Genetic Algorithm (GA), and Fuzzy [38].

(Req-5) Processing units for PEE protection system must have capability of realizing new intelligent and heuristic algorithms

There is a necessity in protection philosophy that similar protection in one place must have discrepancy with each other. Namely the main and backup protection must different algorithms different power supplies and different trip circuit. The (Req-5) has totally agreement with this philosophy and it is a kind of its development.

c) ***Circuit Breaker Unit***

Base on the protection rules, each protection system zone must have its own disconnector like a circuit breaker [29-32]. In primer protection and fuses, this unit is united with processing unit and measuring unit.Power electronic equipment has two main characteristics which cause the conventional MCB being insufficient for their electrical protection. The first, the power electronic equipment faults are fast and they have very fast transient behavior. Therefore, the multi millisecond operation time of MCB is not enough for fault clearance of power electronic equipment faults [39]. Furthermore, the power electronic equipment have limited voltage and current normal range and they thermal capacities are low due to their solid state structures. Other power system equipment like transformers and transmission lines can withstand more over voltage and over current from some tenth seconds up to minutes [3], but PEEs cannot tolerate some over current and over voltage in domain and time. Actually power electronic equipment is more sensitive than other power system equipment [39]. These restrictions cause they need to fault current limiters [2]. Another problem is that the MCBs have some limitations for DC current breaking which DC currents are used many in the power electronic equipment [39, 40].

(Req-6) Disconnection units for power electronic equipment protection system must have enough speed and response time for disconnection the PEE from grid.

Solid state switches are the best solution for fast current disconnecting. Although there are some difficulties in their producing currently, but fortunately, the current technology has developed up to medium voltage circuit breaker as solid state switches with good and proper parameters [39, 27, 3].

3. The Proposed Protection Scheme

PEEs connect to grid in series, parallel and series-parallel. There are especial connections like back to back connection also [1, 7]. Therefore, a general scheme for protection and connection of PEE is proposed in Figure (2).

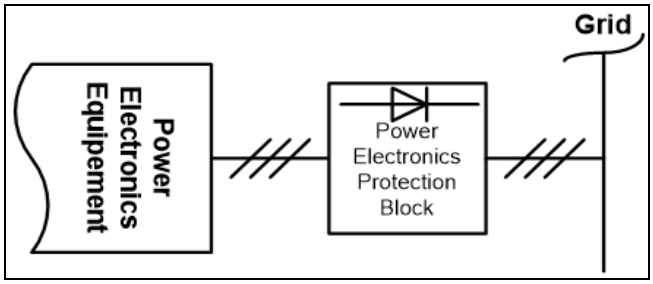

Fig 2: The Connection of proposed protection block

The proposed protection block has measuring, processing, disconnecting and communication unit as shown Figure (3). This block must be used in each connection point of PEEs. Two blocks are used for a UPFC connection like Figure (4).

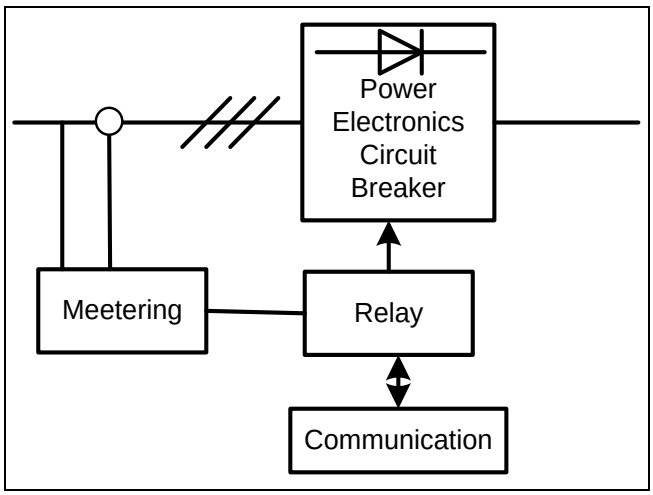

Fig 3: The proposed protection block

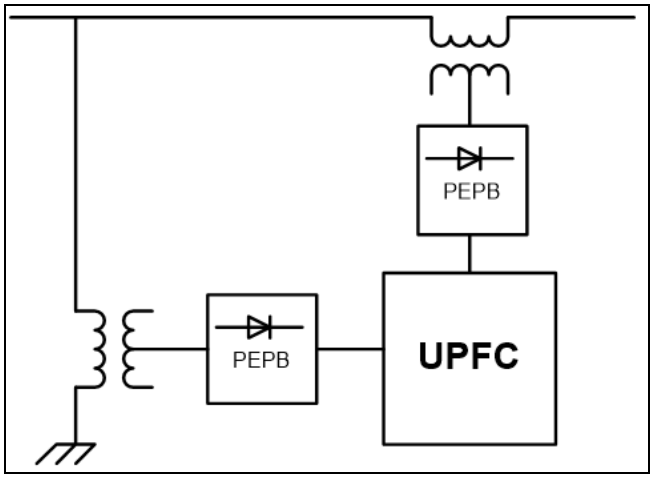

Fig 4: Connection of UPFC with two proposed protection blocks

The proposed protection block has communication unit for data changing for other protection blocks, tele-protection system and SCADA.

Main debatable part of introduced blocked is cost, power loss and space of Power Electronic Circuit Breaker (PECB). But this device has some additional benefits like possibility of soft starting and current limiting.

d) ***Powe Loss of PECB***

The suggested PECB increases overall power loss. This loss covers cooling loss, conduction loss, and control unit consumption loss [39, 41]. This loss is about one percentage to two percentage of the total system power loss [42]. This loss is very noticeable in long duration time. This item is only disadvantage point of proposed PECB in comparison to MCB [39]. Fortunately, new inventions are doing for lower loss and faster switches.

As engineering view, a protection system designer must ponder economic factors. For example, a distribution transformer has simple protection system (only a cut-out fuse) but a transmission transformer has a complicated protection system with many protection relay functions. Using power electronic circuit breaker for in some applications like Wind Energy Conversion Systems (WECS) can be more profitable because of high maintenance cost and their high failure rate.

e) ***Space of PECB***

A produced PECB with IGBT has volume of 23"by9"by11" and 60lb for 10kV and 8MW [4]. This PECB is equivalent with medium MCB of Schneider Electric for 2.4kV to 17.5kV with volume of 90" by 14.75" by 37.25" and 465lb [47]. The current transformer and voltage transformer are considered in this assessment. In future, PECB will have more priority on mechanical circuit breakers [41, 39].

f) ***Cost of PECB***

Cost of a PECB is less than three times of an equal mechanical circuit breakers [27]. Usually power electronic equipment is installed in the lower voltage and lower power of nominal voltage and lower power of system (rather than the other parts) like STATCOM and power electronic converters of WECS. Therefore, power electronic circuit breaker total cost seems to be lower. EPRI is analyzed cost of PECB in different cases [43, 39].

Another point is that (base on existing) statistical five percentage to thirty percentage of breakers from twenty percentage of power grids need to change in the next ten years because of increasing short circuit current level of power systems. This fact makes the proposed block (using PECB) closer to real economic justification [39].

5. Some New Protection Function

As mentioned, power electronics have very varieties in applications, configurations, control, size, voltage, connection etc. Conventional protection function like over/under voltage, over/under current, differential and impedance are not suitable for PEE protection [3, 9, 15, 44]. Harmonic and nonlinearity effects of PEC add more complexity for protection functions. Also there are some faults in PEC that there are not any protection functions for them like open switch fault [45]. Some new protection functions are proposed here only for future studies.

g) ***Harmonic protection function***

It is possible to defining some harmonic protection function like Over THDv, Over THDi and specific harmonic components.

h) ***Power switchs status protection function***

Power switched Status of PEC is detected and the PEC protected against different switch faults [45].

i) ***Pulse Width Modulation protection function***

Some protection functions must be defined for Pulse Width Modulation (PWM) of PECs.

j) ***Loss protection function***

Loss protection can be an important protection scheme for PEE. It is possible to defining some protections schemes on this subject for example power differential in [46].

6. Some PECB

Introduced power electronic circuit breaker is most important part of proposed protection block. PECB can have different names like Solid State Circuit Breaker (SSCB), Static Switch (SC), and Solid State Breaker (SSB). Some basic schemes of power electronic circuit breaker are presented in Figure (5). The main points of power electronic circuit breaker are:

- They do not have Normally Close (NC) contact.
- They have closing voltage drop.
- They are made from one-direction semiconductor switches [13].

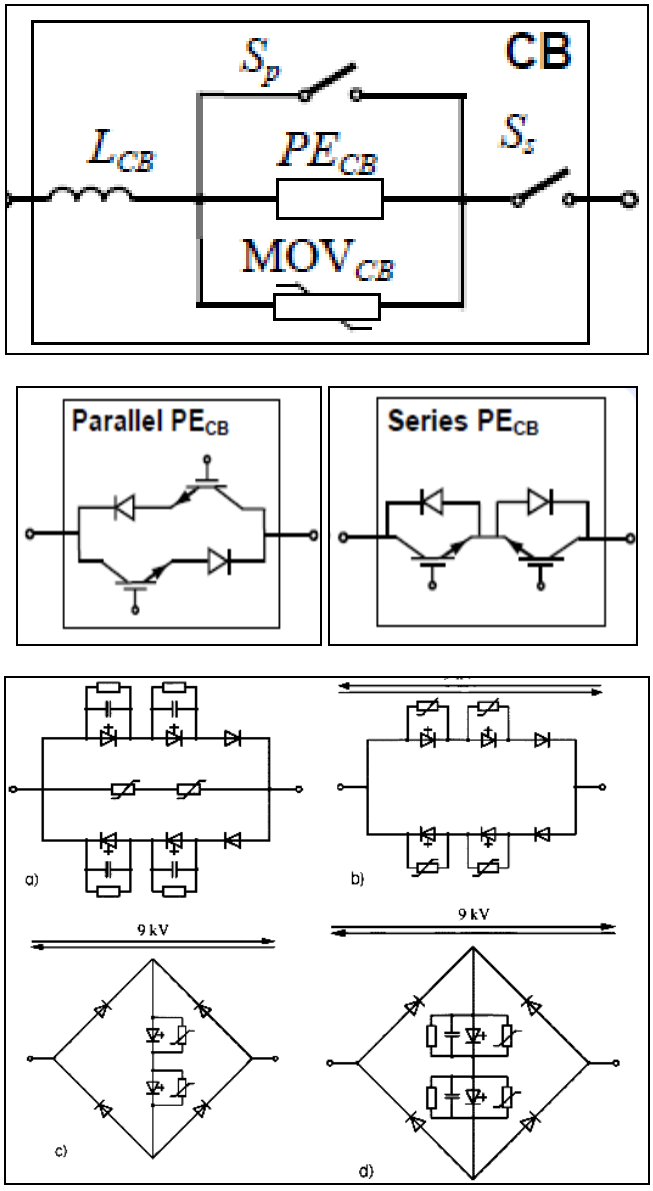

Fig 5: Some basic circuit for PECB

7. Conclusion

Problems and limitations of conventional protection systems for protecting PEE are discussed in this paper and then some vital requirements for protection systems of PEE are mention in this paper base on relay protection principles. A general protection block is proposed for considering the mentioned requirements.

This paper has had technical view to this issue and economical assessment must be done for practical design of a protection system for a PEE.

This paper has started some new topics for protection of PEE in different parts like measuring units, processing unit and disconnection unit. Many researches must be done in continue.

Increasing PEE in very soon coming future makes this paper subject very critical for power systems.

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