

Marina Ground Fault Leakage Current and the NEC

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Article 555 of the 2014 National Electrical Code, “Marinas and Boatyards”, has been re-titled in the 2017 edition to “Marinas, Boatyards, and Commercial and Noncommercial Docking Facilities”. Along with the new title, there are important changes and additions including a very important revision. The revised rule, Section 555.3, has reduced the maximum permitted ground-fault protection from 100 mA¹ to 30 mA and applies that requirement to all overcurrent protective devices (OCPDs) installed in any facility or installation covered by Article 555.

555.3 Ground-Fault Protection. The overcurrent protective devices (OCPDs) that supply the marina, boatyards, and commercial and noncommercial docking facilities shall have ground-fault protection not exceeding 30 mA. ^a

^a2017 National Electrical Code, ARTICLE 555 — Marinas, Boatyards, and Commercial and Noncommercial Docking Facilities

The 2014 code rule requires that the ground-fault protection not exceeding 100 mA be applied at the main service feeding the marina, but permits placement at each individual branch circuit breaker (typically at the pedestal) or the feeder circuit breaker as a suitable alternative. The new 2017 code rule requires that *ALL* overcurrent protective devices in marinas, boatyards, and at commercial and noncommercial docking facilities include ground fault protection not exceeding 30 mA. Reading further in the article, one finds that this requirement does not override the requirement for Class A GFCI protection (5 mA) for almost all marina and dock convenience receptacles. This reduction in the ground-fault trip level was driven in large part by the The Fire Protection Research Foundation. The rationale for their conclusions and list of participants is found in their report *Assessment of Hazardous Voltage/Current in Marinas, Boatyards and Floating Buildings*.²

Anyone involved with marina electrical installations and their operation must consider the potential negative consequences that could result if this new rule is not applied thoughtfully and reasonably in the field, especially as it relates to shore power service to watercraft. It is also important to note that Article 555 makes no distinction between freshwater and saltwater marine environments, even though there are significant differences, electrically speaking.

¹milliamperes

²Assessment of Hazardous Voltage/Current in Marinas, Boatyards and Floating Buildings, Final Report, November 2014, Fire Protection Research Foundation

All electrical equipment and wiring produce small amounts of leakage current. There is no way to eliminate it entirely; a fact borne out by IEC Standard 950 which defines the maximum allowable leakage current for hand-held, movable, and stationary electrical appliances. The limit for movable (other than hand-held) and stationary appliances is 3.5 mA. Interestingly, this number falls just below the minimum trip current for a Class A ground-fault circuit interrupter. If leakage currents exist in land-based electrical systems, they surely exist in marine environments, often at levels greater than 3.5 mA; a fact verified by the ground-breaking investigative work of James Shafer and Capt. David Rifkin³.

The US Coast Guard funded a study³ to investigate electrical conditions in the waters of typical marina facilities (freshwater and saltwater). The study found that leakage currents exist in the water at levels ranging from low milliamperes to multiple amperes per vessel. This study also concluded that currents of less than 100 mA associated with a single vessel in freshwater did not constitute a hazard to an individual immersed in the adjacent waters. The danger threshold for leakage current in saltwater marinas is 500 mA which suggests that higher levels of “normal” leakage current could be, and often are, present.

In any marina there exists a nearly infinite number of leakage current scenarios. Leakage current measurements vary from boat to boat, even in situations where all boat and dock equipment and wiring are in good working order. A survey of 15 boats at rest in their slips in a freshwater marina—all connected to shore power service—yielded leakage current readings ranging from 0.0 mA to 15.5 mA; an average of 3.9 mA per boat. Based on this data, it is certainly reasonable to assign an average leakage current of 3 mA for each slip/boat in the following marina scenario. Also of interest, the current readings on the equipment grounding conductors of the two circuits feeding these slips were 74 mA and 87 mA.

Consider an elementary electrical distribution system in a small freshwater marina (Figure 1 on page 3) providing shore power service to the marina’s five docks. Each dock feeder is protected by an appropriate overcurrent protective device. Each dock has 12 power pedestals with each ped serving two slips for a total of 24 shore power receptacle outlets per dock. Each receptacle has its own local overcurrent protection. Using an average leakage current of 3 mA for each slip in the marina, we find that the individual currents accumulate to a total of 72 mA at the respective feeder circuit breakers, and 360 mA at the main circuit breaker. This is an obvious problem if all of the circuit breakers are designed to trip at a leakage current of 30 mA. Increase the average leakage current for each slip to 10 mA and the accumulated leakage current will be 240 mA at each of the feeder breakers, and 1.2 Amps at the main breaker. These estimated currents originating at each slip in our marina are actually quite small considering that the ‘safe’ margin for any one slip is a leakage current less than 100 mA in fresh water. The “normal” leakage currents are typically much higher (but not necessarily more dangerous) in a saltwater marina, exacerbating the problem.

Table 1 provides the accumulated leakage currents to be found at each feeder breaker and at the main breaker for a variety of average slip leakage currents in the freshwater marina example. These numbers would be much larger for a saltwater version of the marina where “normal” leakage currents can be multiples of the numbers in the table.

³USCG FY2006 Grant, In-Water Shock Hazard Mitigation Strategies, Final Report, October 1, 2008, James D. Shafer and Capt. David E. Rifkin (USN, Ret)

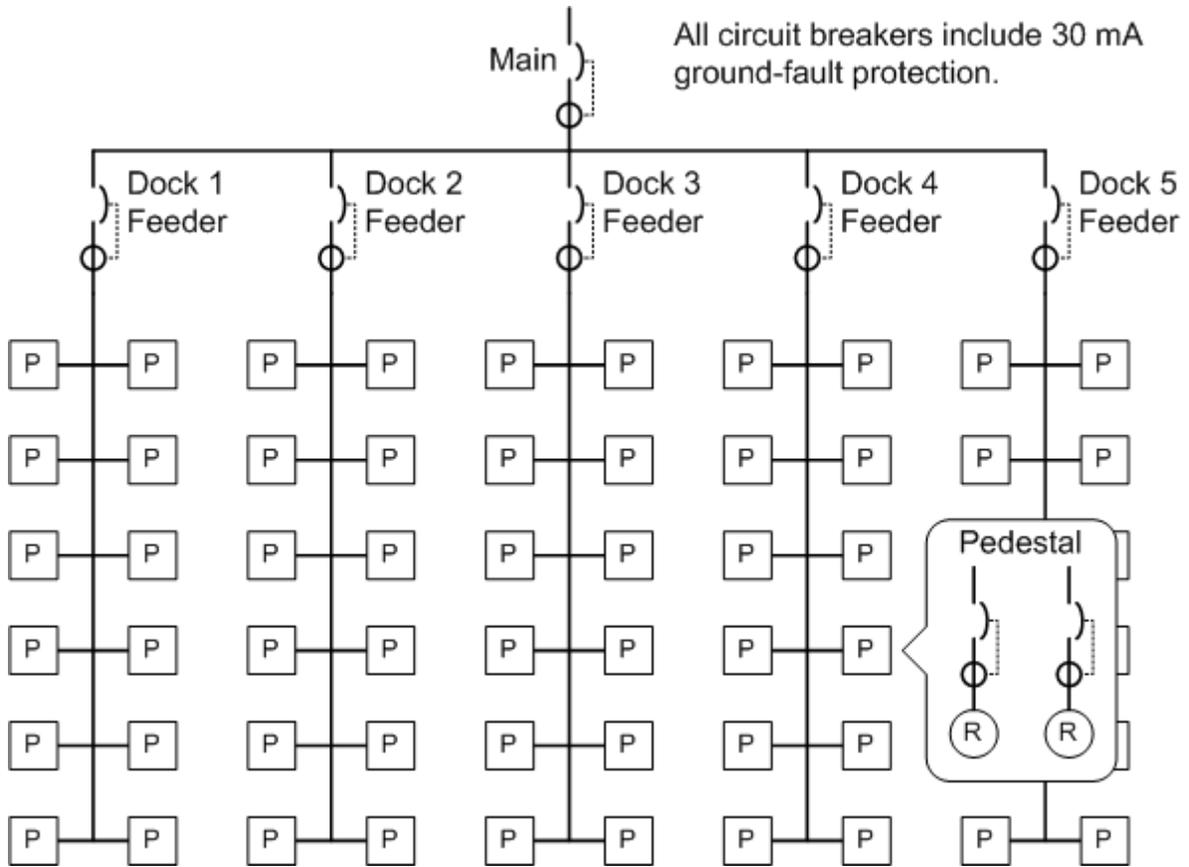


Figure 1: Marina Electrical System

Table 1: Leakage Current Accumulation

Average Current / Receptacle (mA)	Total Current at Feeder CB (mA)	Total Current at Mains CB (mA)
1	24	60
2	48	120
3	72	360
4	96	480
5	120	600
10	240	1200
20	480	2400
30	720	3600
50	1200	6000
100	2400	12000

A quick survey of several marina dock feeders during the 2016 boating season yields some interesting real-world numbers. Measurements on 12 different feeders at a Red Wing, Minnesota marina (on the Mississippi River) found leakage currents ranging from 40 mA to 240 mA. In no case did the current on any one shore cord approach a level that raised concerns. Another smaller Red Wing marina with two feeders indicated levels of 700 mA and 550 mA. Again, the current on any one shore cord did not approach a level that raised concerns. It is not difficult to see how the new maximum trip level of 30 mA could render useless the dock electrical distribution systems in each of these marinas. A more detailed analysis of such facilities is planned for 2017. This effort will include checking of the electrical systems both before any boats are in the water and after all boats are splashed and connected. It is possible that substantial non-watercraft-induced residual currents exist at some facilities due to nearby or surrounding power distribution networks.

The marina example above and the field measurements raise important questions regarding the application of ground-fault protection to marina feeders and mains. While limiting overall ground-fault protection to 30mA for an entire facility may not be a problem for private docks and very small commercial facilities, it portends big (possibly insurmountable) challenges for medium and large commercial marinas where false tripping of circuit breakers would become a massive and unmanageable nuisance.

The American Boat and Yacht Council (ABYC) recommends that boats wired for AC shore power service be fitted with an on-board Equipment Leakage Circuit Interrupter (ELCI) that trips at 30 mA. ELCIs (Figure 2) will be found on newer boats and are of particular benefit where the shore power service does not include suitable ground-fault protection at the point of connection (still the case at a great many marinas). The 2017 NEC requires that new marinas, and those that are upgraded, be equipped with circuit breakers having ground-fault protection not exceeding 30 mA. All breakers are included in this requirements, be they branch circuit, feeders, or mains. Where present, the 30 mA GFP provides essentially the same protection as an ELCI. This will protect boats that do not have on-board ELCIs. The fact remains that countless numbers of older boats berthed in innumerable older marinas where wiring has not been updated will not have this protection. It could be many years before the 30 mA level of protection is universal throughout the US unless additional regulations are put in place.



Figure 2: Marine ELCI

30 mA ground-fault protection at the pedestal makes good sense and will provide a greater degree protection than the currently required 100 mA. The fact remains that feeders serving multiple receptacles must have higher trip levels—at least 100 mA, possibly higher. Existing installations may require rewiring of existing feeders to serve fewer pedestals. Main breakers should be equipped with adjustable ground-fault protection or ground-fault monitoring equipment adjusted to accommodate the real-world conditions for the specific installation. GFP Alternative 1 (Figure 3 on page 6) depicts a barely workable scenario for proper GFP coordination, although it would still be susceptible to false tripping. GFP Alternatives 2 through 4 (Figures 4 through 6 on pages 7 through 9) each improve on the previous scenario by reducing the accumulated leakage current.

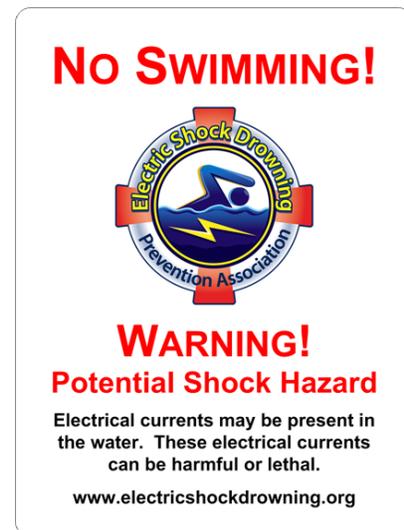
GFP Alternative 5 (Figure 7 on page 10) would be the least problematic and most reliable solution as there is no accumulated leakage current at a feeder breaker. Two added benefits are achieved with Alternative 5. First, the entire dock wiring system along with the connected vessel is protected at 30 mA. Second, all circuit breakers are single-pole which eliminates concerns that have arisen regarding use of 2-pole GFP breakers in marina facilities.⁴ Engineers and contractors will, of course, note that the increased stability and reliability comes at an increased cost. All of these alternatives comply with the 2014 NEC by including ground-fault protection of 100 mA or less and meet the spirit of the 2017 NEC by limiting the ground-fault protection at the pedestal receptacle to 30 mA. Unfortunately, none of these alternatives comply with the 2017 NEC as currently written.

As in most areas of life, protection of the public from hazardous conditions has its practical limits. Extending rules and regulations beyond those limits all too often produces negative results where practical necessity encourages the defeating or bypassing of the very measures intended to protect.

It is the author's belief that field experience with the 2017 rule will necessitate a rewrite of 555.3 for the 2020 NEC. In the meantime, engineers, designers, contractors, inspection authorities, and marina operators will likely find this new requirement a significant challenge. Careful planning, design, and coordination of distribution architecture will be required for new facilities, and for upgrades to existing facilities. Field measurements made after installation could require modifications or adjustments to an initial design.

A FINAL COMMENT

PLEASE keep in mind that compliance with codes and safety standards will help to protect an individual that inadvertently enters the water around a dock or boat equipped with electric power. Compliance with codes and safety standards should NEVER be perceived as a "green light" for recreational swimming or other in-water activities around such docks or boats. The 2017 NEC reinforces this position by including a new requirement (in new section 555.24) that mandates warning signs at all approaches to dock facilities where electricity is in use. It even goes so far as to specify the minimum acceptable wording. These warning signs (similar to the one shown here), along with proactive education of the public, are a great and inexpensive way to enhance personal protection for marina customers and staff—and reduce a marina owner's exposure to liability claims.



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⁴Ground-Fault Protection and the Multi-wire Branch Circuit: A Troubled Marriage, Randal P. Address, August, 2016

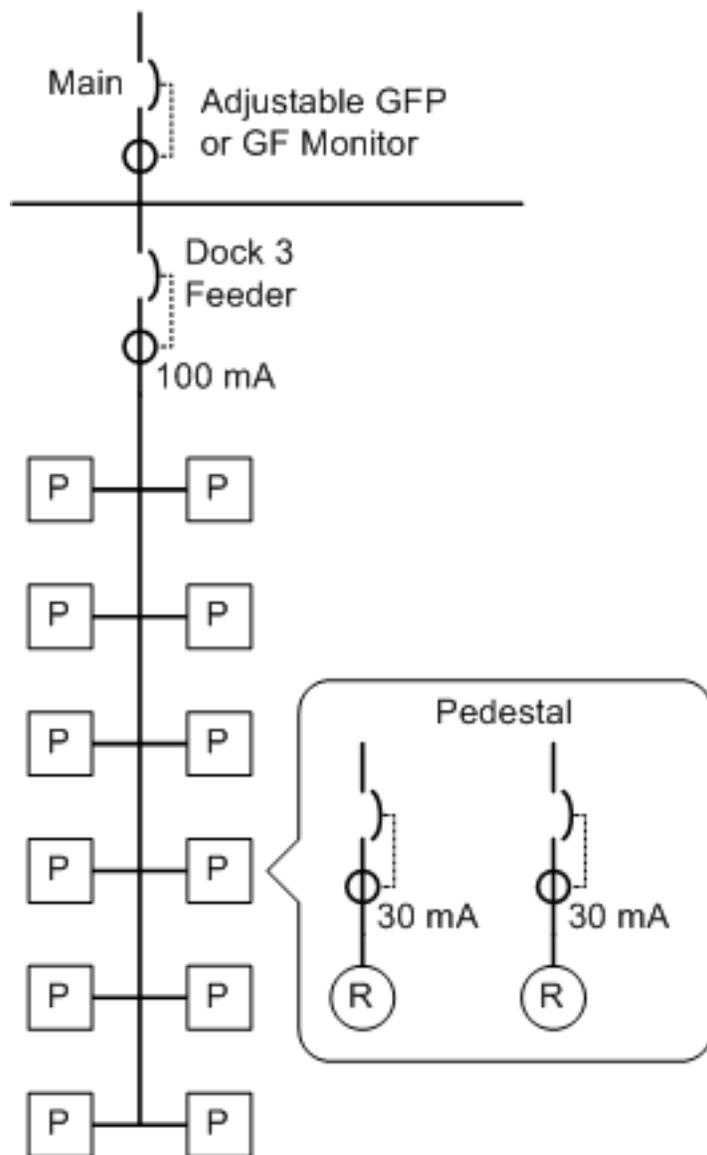


Figure 3: GFP Alternative 1

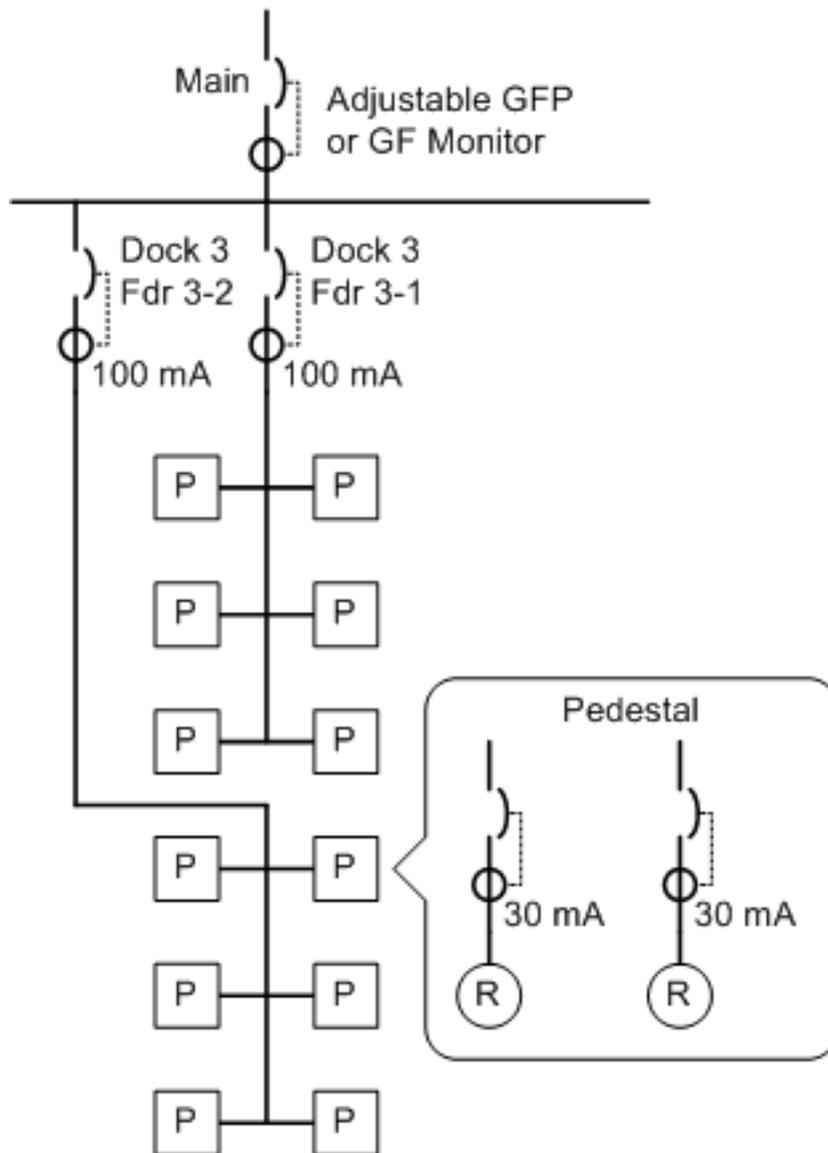


Figure 4: GFP Alternative 2

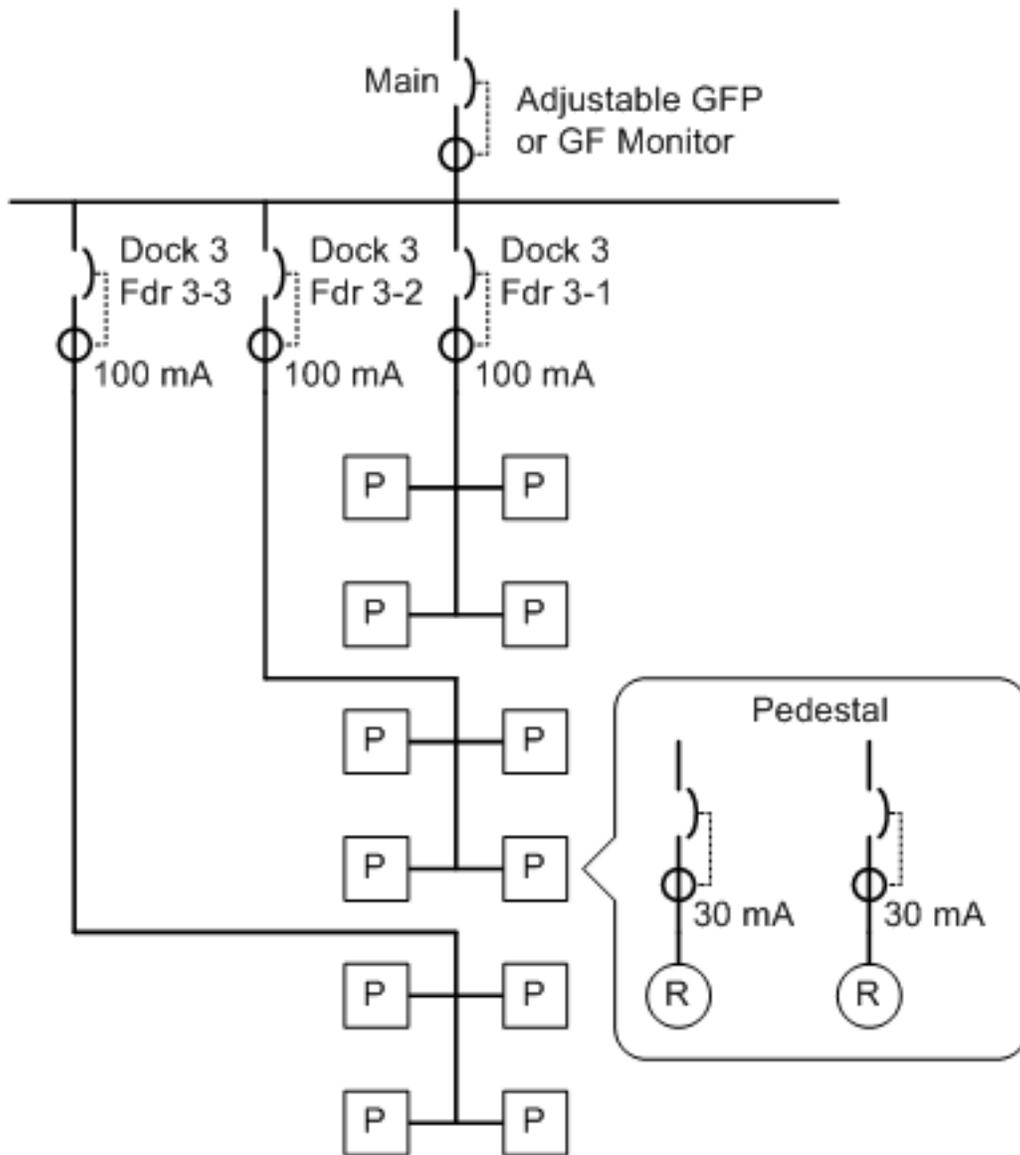


Figure 5: GFP Alternative 3

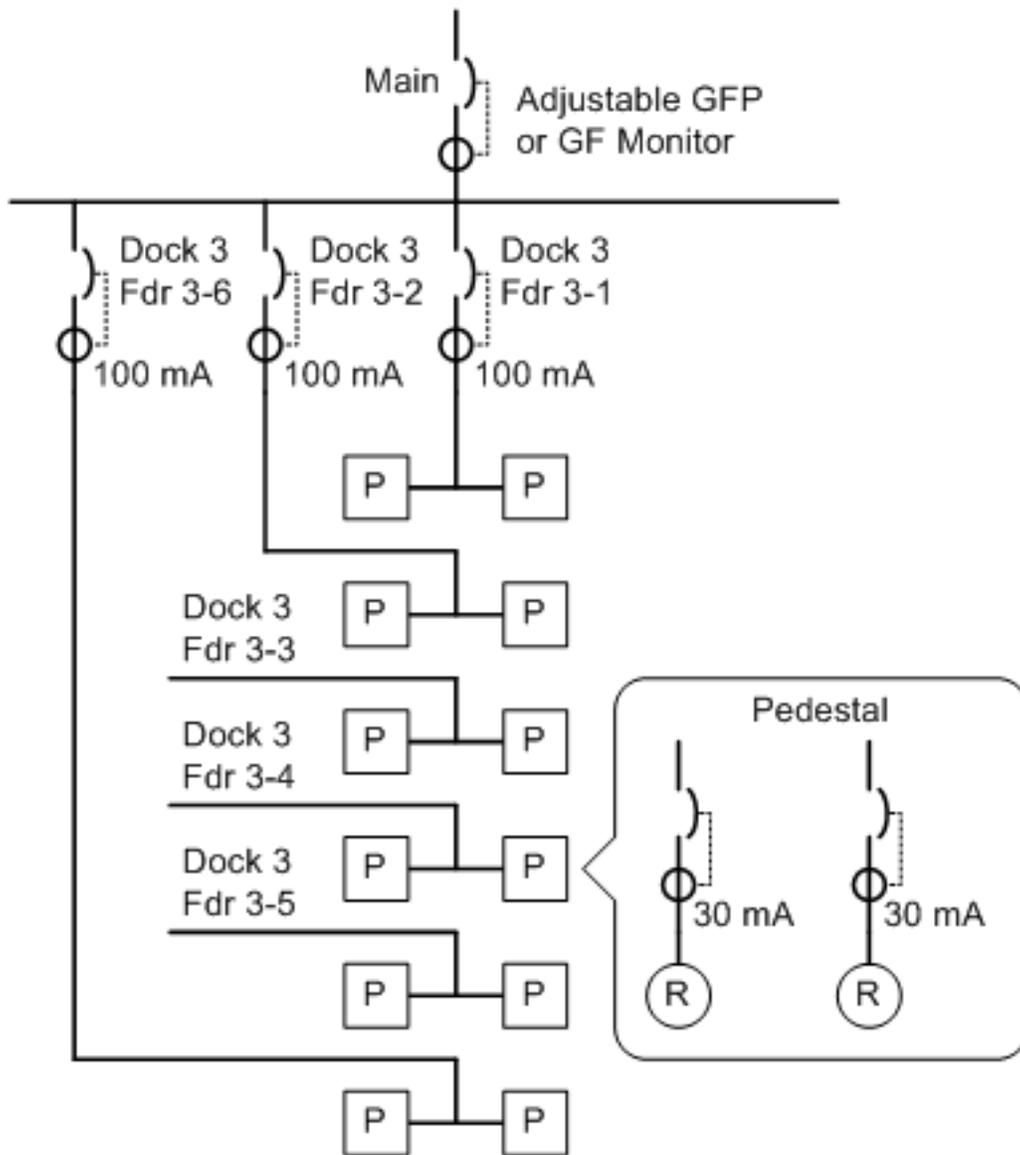


Figure 6: GFP Alternative 4

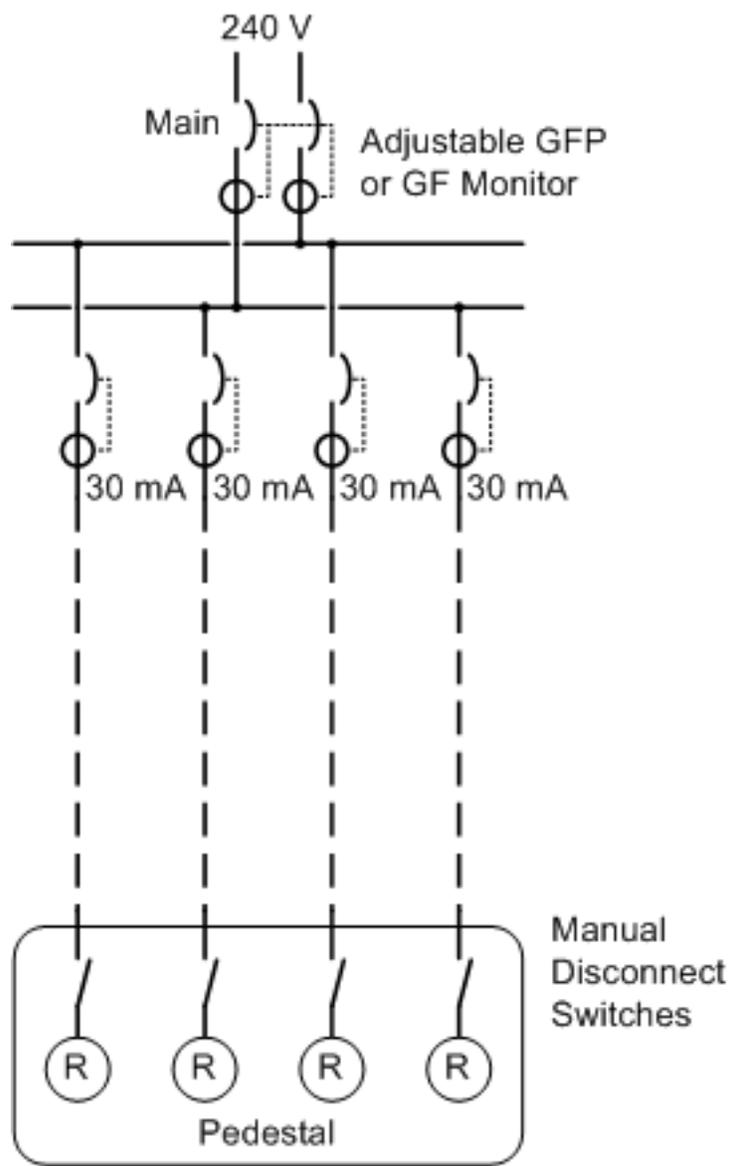


Figure 7: GFP Alternative 5