1. INTRODUCTION

The purpose of this note is to illustrate the advantage of FGRs over FTRs in providing hedge cover for congestion costs associated with efficient transactions. For simplicity we will use the three node example shown in Figure 1 below that has been introduced in the CPOW paper and used repeatedly in the RUFF-OREN debate. Figure 2 shows the nomogram that defines the set of all feasible injections of generators 1 and 2 and also the set of all possible combinations of FTR 1→3 and FTR 2→3 that can meet the simultaneous feasibility constraints when FTRs are defined as two sided entitlements/obligations. We will make the standard assumptions of a lossless DC model with constant PTDFs and fixed lineflow (Flowgate) capacities. The validity of these assumptions in practice is still being debated but that is not the issue addressed by this note.

The congestion charges collected by the RTO in real time and the FTR settlements are based on the respective LMP differences corresponding to the actual operating point within the nomogram. That operating point (assumed to be the OPF solution) could be different than the point describing the mix of outstanding FTRs. The simultaneous feasibility constraint imposed on the FTRs issued by the RTO is necessary and sufficient to guarantee revenue adequacy for the RTO under any operating point within the nomogram, i.e., simultaneous feasibility guarantees that the net real time congestion payments collected by the RTO will cover the net FTR settlements. If FTRs are defined as options i.e. the FTR holder is not obliged to produce counterflow or pay a negative
settlement, then the simultaneous feasibility condition would allow the RTO to issue FTR combinations in the region O-A-X-Y-E-O shown as the light shaded area in Figure 2.

The boundaries of the feasible region illustrated in Figure 2 correspond to binding directional line flow constraints as marked. The number of feasible FGRs that can be auctioned off by the RTO (in each direction) based on the physical capacity of the lines (flowgates) is given by the line capacities shown in Figure 1. Additional flowgate rights can be issued in each direction if they are matched by counterflow obligations in the opposite direction. Such counterflow obligations can increase the number of FGR 1→2 and FGR 2→1 that can be auctioned off by the RTO. Such counterflow obligation are needed in order to create full congestion hedge cover for dispatches that fall on the boundaries A-B and D-E. The settlement rule for FGRs is to pay each MW right (or charge each MW of counterflow obligation) the shadow price of the flowgate corresponding to the actual real time dispatch. This implies that no payment is made or received for FGRs corresponding to nonbinding flowgates.

In the following analysis I will assume a more restricted world than that envisioned in the CPOW paper where the RTO issues FGRs backed by the physical capacity of the flowgates while counterflow obligations are handled through private trading. Specifically, I will assume here, for simplicity, that all FTRs or FGRs are issued (or acquired) by the RTO. In other words we will exclude (just for the sake of this discussion) the possibility of privately issued FTRs and FGRs. Unfortunately, the idea of private FGRs has confounded the debate and led to the erroneous impression that private FGRs are essential for an FGR based system. We will also assume a simple secondary market (with no rocket scientists) that will allow secondary trading of RTO issued rights but no private conversion of such rights (e.g. through issue of private rights that are hedged by different RTO issued rights). We will assume that reconfiguration auctions by the RTO are the only mechanism for conversion of FTRs. This is apparently a realistic assumption given the report by Andy Ott attesting to the virtual nonexistence of a secondary FTR market at PJM.
The question of what type of rights provides better hedging cover against congestion cost can be broken in two parts.

- Will individual traders be able to obtain full hedging cover for the congestion charges associated with their forward energy contracts?

- Can the outstanding rights provide full hedging cover (in the aggregate) for the congestion costs associated with every possible real time transaction?

An affirmative answer to the second question is a necessary but not sufficient condition for the first. However, even if the hedging instruments necessary to cover all congestion charges have been issued by the RTO, having them in the right hands depends on the efficiency of a secondary market. I personally believe, for reasons given in the CPOW paper and the RUFF-OREN exchange that a secondary FGR market is likely to be more liquid and efficient than a secondary FTR market (which is evidently nonexistent at PJM). However, since that assertion is still debatable I will focus on the second question above for which an objective answer can be obtained. So the question that I will address is whether the outstanding RTO issued rights under an FTR and under an FGR system can provide full congestion hedge cover for all possible feasible dispatch configurations. This question will be examined for the two case: when rights can also entail obligations and when rights are only issued as options.
It is important to realize that while the nomogram in Figure 2 describes all possible transactions, the issue of hedging is moot for any dispatch in the interior of that nomogram. An interior operating point implies an unconstrained optimal dispatch. The LMPs corresponding to such a dispatch are all equal and the corresponding shadow prices on all flowgates are zero so are no congestion charges and no FTR or FGR settlements. Thus, the only dispatches of interest in terms of hedging capability are represented by the boundary of the nomogram.

**FIGURE 2**
2. ANALYSIS

CASE A: FTRs and FGRs can represent rights and obligations

In this case the RTO can issue any combination of FTRs corresponding to any point in the nomogram. However, if we exclude the possibility of bid deficiency (assume that bidders will bid at least a penny for all FTRs that they do not want just in case no one else bids for them) then the combinations of issued FTR will be on the boundary of the nomogram (the heavy red line between point A and point E). Let us assume that the FTR auction resulted in a mix of FTRs represented by point Z. This mix, which is typically chosen by the RTO so as to maximize auction revenues, will represent the outstanding FTRs until the next reconfiguration auction which is conducted periodically (monthly at PJM). Now let us assume that the real time operating point is any point other than Z on the Monogram boundary (if it an interior point than there is no congestion). Assuming that the operating point is optimal with respect to some objective function and subject to the constraint set represented by the nomogram, then the real time congestion rents will exceed the FTR settlements. This result, which is the underlying reason for the simultaneous feasibility test for FTRs, was proven by Bill Hogan in his seminal 1992 paper on contract networks. It follows from the fact that the point Z is a feasible suboptimal power flow solution of the real time OPF problem.

The flip side of the over collection by the RTO is under hedging by the traders. In other words The excess revenue retained by the RTO after collecting congestion charges and paying off the outstanding FTRs means that some congestion charges were unhedged. So the revenue adequacy and the simultaneous feasibility condition, which are the linchpin of the FTR approach in fact, guarantee that unless FTRs are continuously reconfigured by the RTO to track the real time operating point some congestion charges will be unhedged.

In an FGR world, the RTO auctions off all the FGRs corresponding to the flowgate capacities and additional FGRs (to the extent that they are feasible) backed by counterflow obligations. For instance, The RTO can sell up to 133MW of FGR 1→2,
which 33MW are backed by FGR obligations. However FGR obligations on that flowgate beyond 33MW would not be feasible since scheduling them would violate other flowgate constraints. For flowgates that are unlikely to be constrained the FGR (commercially significant) prices will be zero and the RTO can either allocate them based on historical use or keep them. In real time the RTO collects congestion rents based on the LMPs associated with the operating point and the FGR holders are paid the shadow prices of the flowgates corresponding to that point. In Linear programming terms, the problem of maximizing the FGR total real time revenue is the dual of the OPF problem minimizing dispatch cost. It therefore, follows from the strong duality theorem of Linear Programming that if the operating point is an OPF solution then the payments to the FGRs exactly equal the congestion charges based on LMP. In other words, the in an FGR world the RTO distributes all the congestion revenues to the FGR holders so that regardless of the operating point all the congestion charges are fully hedged. The above observations are formally summarized in the following theorem.

**Theorem I:**

Assuming constant PTDF, and fixed flowgate capacity, then

1. A maximal feasible set of permanent FGRs (including rights and counterflow obligations) issued by the RTO will provide in the aggregate better or equal hedge cover for real time congestion cost as compared to a maximal set of simultaneously feasible, periodically reconfigured FTRs.

2. A maximal set of FGRs will provide, in the aggregate, a complete hedge of all real time congestion cost.

3. A maximal simultaneously feasible set of FTRs can provide the same hedge cover as a maximal feasible set of FGRs if and only if the FTRs are continuously reconfigured so that the FTR mix tracks the real time operating point whenever congestion occurs.
CASE B: FTRs and FGRs are issued as Options.

We will assume now that neither FTRs or FGRs issued by the RTO can entail obligations. In other word, the instrument holder will not exercise the instrument or be liable for payment if the settlement value of the instrument is negative. In the case of FTRs the above restriction reduces the set of possible simultaneously feasible FTR options to the light shaded region O-A-X-Y-E-O in Figure 2. The RTO cannot issue more then 300MW of either FTRs if he cannot count on counterflow or obligation payment. Furthermore he cannot issue the 300MW of the two FTRs simultaneously since such a combination would fall out of the nomogram. A maximal set of FTR options can result in any FTR mix on the feasible FTR options set boundary X-Y. As before a reconfiguration FTR auction will result in an FTR mix represented by a single point on the boundary and whenever the operating point is different than the FTR mix then some congestion charges will remain unhedged. As implied, however, by Theorem I, the shortfall in hedge cover can be reduced by increasing the frequency of reconfiguration auctions with the maximum hedge cover being achieved when the reconfiguration auction is continuous. The maximal set of congested dispatches, for which continuously reconfigured and simultaneously feasible FTR options can provide full congestion hedge cover, is given by the line segment X-Y in Figure 2. For any other transactions on the nomogram boundary there wouldn’t be enough FTR options due to the simultaneous feasibility requirement.

Now let us turn to FGR options. Since shadow prices on constrained flowgates are nonnegative, FGRs corresponding to the physical capacity of the flowgates can be issued as options in the full quantities that reflect these capacities. However, in the absence of FGR obligations the RTO cannot issue the additional FGRs that are backed by counterflows without incurring financial liability. Consequently as pointed out by Ruff, congested dispatches corresponding to segments A-B and D-E on the nomogram boundary in Figure 2 cannot be fully hedged against congestion charges. However, this hedge cover deficiency only occurs when the flowgates constraints between nodes 1 and 2 is binding. If the constraint is not binding the shortage of FGR 1→2 and FGR 2→1 due to lack of counterflow obligations is moot since these flowgates do not contribute either to the congestion charges or to the FGR settlement. It follows that in the absence of
FGR obligations only dispatches on the positive sloped segments of the nomogram boundary will suffer from a deficiency of congestion hedge cover. In other words any transaction or dispatch on the segment B-C-D of the nomogram boundary, excluding the points B and D (open set) can be fully hedged for congestion cost with FGR options. Clearly this set of dispatches is substantially larger than the set X-Y that could be hedged with FTR options under the best case scenario of continuous reconfiguration. As the network increases in complexity the set of FTRs that can be issued as options and still meet simultaneous feasibility shrinks leaving many possible transactions unhedged for congestion charges even when such dispatches are not actively constrained by counterflow on congested flowgates. In Figure 2 for instance, constrained dispatches on segment Y-C of the nomogram boundary cannot be fully hedged for congestion costs with simultaneously feasible FTR options although these dispatches are not constrained by counterflow. By contrast, under the FGR approach only dispatches corresponding to positive sloped segments of the nomogram boundary will suffer from hedge cover deficiency due to lack of counterflow obligations. Such dispatches must involve on congested flowgates (which have positive shadow prices). Hence, it is safe to say that the relative advantage of FGR options over FTR option in providing full hedge cover for congestion cost increases with system complexity. Again I will summarize the above observations in a formal Theorem.

**Theorem II:**

Assuming constant PTDFs and fixed capacity flowgates, then the set of transactions that can be fully hedged for congestion cost with a maximal set of simultaneously feasible FTR options is a strict subset of the set of transactions that can be fully hedged for congestion cost with a maximal feasible set of permanent FGR options. The above holds for any arbitrarily frequent reconfiguration of the FTR options.

### 3. CONCLUSION

The above analysis provides definitive proof that FGRs whether issued as two sided contracts or as options have superior hedging characteristics over their FTR counterparts (i.e., two sided or options). The proofs do not hinge on the existence of privately issued
instruments or the efficiency of secondary markets although secondary trading will be needed to get the hedging instruments into the right hands. This proof settles the issue of whether in theory FGRs are better than FTR in terms of providing hedging capability for congestion charges to support forward energy trading.

The debate will undoubtedly continue on the empirical questions concerning the validity of the assumptions that PTDFs and flowgate capacities are stable and that the number of commercially significant flowgates for which FGRs should be issued is reasonably small.